INVENTORIES OF APPARATUS AND MATERIALS FOR TEACHING SCIENCE. VOL. III, PART 4

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INVENTORIES OF APPARATUS AND MATERIALS FOR TEACHING SCIENCE

VOLUME III

TECHNICAL COLLEGES

PART 4

ELECTRICAL ENGINEERING

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UNESCO

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PREFACE

EDUCATIONAL and cultural rehabilitation has been, and still is, one of the chief problems confronting the post-war world. Educational and cultural centres, such as schools, colleges, laboratories, libraries, museums, were either destroyed or looted on a large scale during the last war. The task of restoring them to their pre-war conditions has been vast and it is far from being completed. In addition there has been an awakening to the urgent need for expanding all forms of education especially in underdeveloped regions.

Everywhere there is an increasing awareness that it is important to provide greater facilities for teaching science and technology. This trend is obviously due to the immense changes that science and technology have produced in man's ability to understand nature's mysteries and to control and utilize its forces for his purposes. It is not surprising, therefore, that wherever peoples are confronted with low standards of life and try to improve them, they turn to science and technology.

To implement the plans that have been prepared for the adequate teaching of science in schools and colleges in the war-damaged and in the underdeveloped regions is admittedly a long-range enterprise. Any guidance towards improved techniques in this field of education would surely be of great help to the authorities concerned. For this reason, Unesco is presenting, together with the corresponding curricula, a series of inventories of apparatus and materials for teaching science at all levels. It is hoped that these publications will be useful to educators as reference manuals for selecting essential equipment from the lists commonly used in some of the leading countries; for clarity the lists are related to corresponding curricula. By diffusing information of this comparative kind on the training of students, the inventories may well contribute also to bringing about equivalence of degrees and diplomas in science and engineering, irrespective of the universities and institutions where they are awarded.

Such an approach to the problem of scientific reconstruction was initiated by the Conference of Allied Ministers of Education, which was first held in London in 1943. The Science Commission set up by that conference issued in 1945 a limited set of inventories of basic scientific equipment as an *aide-mémoire* to the governments of occupied Europe, to assist them in rehabilitating scientific education.

Unesco inventories are being published in three volumes and in several languages: Volume I contains information bearing on primary, secondary and vocational schools; Volume II deals with universities, and Volume III with the technical colleges.

For reasons of convenience, Volume III is published in separate parts. The first three deal respectively with the teaching of veterinary sciences, with the training of engineers having specialized knowledge of physics and chemistry, and with the teaching of agricultural sciences. The fourth and present part deals with the training of electrical engineers. It contains three subdivisions in which will be found information about the organization of the teaching of electricity at the École Supérieure d'Électricité (France), the Royal Technical College, Stockholm (Sweden), and in Great Britain.

While the prices of items of equipment are mentioned in the inventories in U.S. dollars whenever possible, these should be taken as more indicative than exact, owing to the prevailing fluctuations both in the cost and in the quality of available apparatus. However, when a specific request arises for more detailed and up-to-date information for installing a school or a college laboratory, Unesco will attempt to furnish the answer.

Unesco desires to express its thanks particularly to the École Supérieure d'Électricité, of Paris, in the person of the Assistant Director, Colonel Bédoura, to the Kungliga Tekniska Högskolan, Stockholm, in the person of Professor F. Dahlgren, and to the Institution of Electrical Engineers, London, in the person of its secretary, W. K. Brasher, who have very kindly provided the elements from which this publication has been synthesized.

FIRST PART

HIGHER TEACHING OF ELECTRICITY IN FRANCE

(at the École Supérieure d'Électricité)

GENERAL ORGANIZATION OF THE SCHOOL

Object and Character of the Teaching

The object of the École Supérieure d'Électricité is to give young people of already advanced educational attainments, a highly specialized course. This teaching is divided into two parts: theory and practical work.

Divisions

It is given in two divisions: those of electricity and of radio-electricity and electronics.

Type of School

The school is a non-residential institution for full-time study. The diploma taken at the end of the course is that of *Ingénieur ESE* (Engineer ESE) or *Ingénieur Radio ESE* (Radio Engineer ESE).

Teaching Staff

This consists of:

1. Professors, in charge of the general courses (electrotechnics, radiotechnics, measurements, etc.); they are normally selected from the general body of university teachers, but have acquired, through long and uninterrupted association with manufacturers, an industrial outlook which inspires all their teaching.
2. The lecturers, professional engineers, who devote part of their time to the school and are especially concerned, in industry, with the subject on which they lecture at the school.
3. The demonstrators, engineers who direct and supervise the practical work in the laboratories or the tests on machines.

Conditions of Admission

In contrast to the practice at the majority of the French *grandes écoles* (higher professional schools), which recruit their students only through examinations, the ESE does so partly through examinations (written and oral) and partly on the presentation of certificates; in either case, the choice between the divisions must be made prior to entrance.

Entrance Examination

Preparation for this examination (common to both divisions) requires in general two years of study after baccalaureat and is carried out in specialized classes of some secondary schools of the Paris region, Paris itself, or of Algeria. While there is no special age or diploma condition for taking the examination, in actual practice all the candidates are at least 18 and have gained the baccalaureat in mathematics. Girls are admitted on the same terms as boys. The proportion of candidates selected from the examination is about 30 per cent, say 150 out of 500 entering.

Tests composing the Entrance Examination

The entrance examination comprises the following tests: French (one written paper), mathematics (two written papers, one of numerical calculations, one oral examination), general mechanics (one written paper, one oral examination), physics (one written, two oral examinations), chemistry (one oral examination), practical physics and electricity (one oral examination), general electricity and electrical machines (one written paper), general electricity (one oral examination), engineering drawing (one written paper). Exemptions from tests can be granted to candidates who hold degrees in certain subjects.

Programme of the Entrance Examination[1]

The candidates must know those parts of elementary mathematics which are necessary to understand the items of the syllabus given below, and they must be able to apply the results, but proofs will not be required from them.

Mathematics

Algebra and analysis[2]

Concept of incommensurable number.[3] Numerical values to $\frac{1}{10^n}$. Approximate calculations.
Division of whole polynomials. Highest common factor of two polynomials.[4]
Arrangements, permutations, combinations (without repetition). Binomial theorem for a positive, integral exponent.[5]
Extraction of roots. Fractional, incommensurable, and negative powers. Determinants. Exchange of rows and columns; exchange of two rows or two columns; combination of rows and columns. Development from the elements of a row or a column. Product of two determinants.
Linear equations.[6] Solution of equations by determinants.
Linear forms. Conditions of independence. Complex numbers. Operations. De Moivre's theorem. Application to the multiplication and division of angles. Trigonometrical solution of binomial equations.[7]

Series. Geometrical progression. Series with positive terms. The series $\Sigma \frac{1}{n^p}$.

Convergence characteristics derived from a study of $\sqrt[n]{U_n}$ and of $\frac{U_{n+1}}{U_n}$.

Series having absolute convergence.[8] Alternating series whose general term decreases constantly in absolute value and tends towards zero.
Approximate calculation of the sum of a convergent series; upper limit of the error. Definition of e: its incommensurability.
Series having complex terms. Multiplication of two absolutely convergent series.[9]

---

[1] Extract from: Société française des électriciens. *Programme des conditions d'admission à l'enseignement de l'École supérieure d'électricité* (Outline of conditions of entry and of teaching at the École supérieure d'électricité). Paris, Librairie Vuibert, 1951, 47 pp.
[2] Teachers should avoid all general theory about the concept of limits and must restrict themselves to making this idea understood with the aid of the examples which the syllabus supplies.
[3] The concept of incommensurable number is to be deduced from the measurement of magnitudes; incommensurables should be defined either by series, or by cuts in the general body of rational numbers. It will not be necessary to give a complete theory of operations on these numbers, and it can be assumed that they are subject to the same rules as the elementary operations of arithmetic. The essential thing is that the pupils know when such numbers are definite, and how they come into numerical calculations.
[4] The condition for which two polynomials shall have a highest common factor of a given order does not figure in the syllabus.
[5] Summation of the number of balls in a pile, powers of a polynomial having more than two terms, apart from the square or cubic terms, are excluded from the syllabus.
[6] The pupils should have had practice in solving simple systems of linear equations using determinants.
[7] De Moivre's theorem, for a non-integral exponent, and the prime roots of a binomial equation are excluded from the syllabus.
[8] There is no point in concerning oneself with the order of the terms in a series which is not absolutely convergent.
[9] Double series are not in the syllabus.

Functions of a real variable. Graphs. Continuity.[1]

Common functions: polynomials, rational functions, explicit algebraic functions; a^x, $\log x$, x^m; circular and hyperbolic functions, direct and inverse. Infinitely small and infinitely large quantities. Comparison of infinitely small quantities. Application to the study of series. Comparison of infinitely large quantities. Limiting value of $\left(1 + \frac{1}{m}\right)^m$ for infinite m.

Derivative of a function: geometrical significance. Differential of a sum, product, ratio, of a quantity raised to an integral power, of a function of a function, and of an inverse function. Derivatives of the common functions.

Successive derivatives. nth derivative of the product of two functions.

Rolle's theorem. Formula for finite increments; geometrical interpretation.

Taylor's theorem.[2]

Use of the derivative as a means of describing the variation of the function of a variable; maxima and minima.

Integrals of a given function.[3]

Complete series, with real coefficients, of a real variable. Convergence interval.[4] Within a convergence interval, the derivative or integral of the function defined by the series is obtained, by differentiation or integration term by term.[5]

Series expansion of $\frac{1}{1-x}$, $\tan^{-1}x$ (arc tan x), $\log(1-x)$, $\log \frac{1-x}{1+x}$; exponential series, and series for the hyperbolic functions; binomial series, arc sin x.[6]

Taylor series. Series expansion of $\sin x$ and $\cos x$.

Rate of increase of e^x and of $\log x$, compared with that of x^m.

Applications of Taylor's theorem, of expansion in series and of the properties of infinitely small and large numbers to the study of varied forms of indeterminate magnitudes.[7]

The functions e^z, $\cos z$, $\sin z$, ch z, sh z for z complex.[8] The equalities $e^z e^{z'} = e^{z+z'}$, $e^{x+iy} = e^x (\cos y + i \sin y)$.

Functions of several real, independent variables. Partial differentials. Derivative of a compound function. Taylor's theorem.[9] Derivative of an implicit function.[10] Euler's identity for homogeneous functions.

Differentials. First differential of a function of one variable. Complete differential, defined by the formula $df = f'_x dx + f'_y dy + \ldots$ Transformation of this expression when $x, y\ldots$ are replaced by functions of other variables. Applications.

Calculations of differentials.[11]

---

[1] All complications inherent in the theory of continuity are to be avoided. It is to be assumed without proof that a function is continuous within an interval (limits inclusive) and has upper and lower limits, in attaining which it passes through all intermediate values. Only continuous functions having a derivative are envisaged.

[2] Only the so-called Lagrange form is dealt with.

[3] The existence of an integral function, for any continuous function, is assumed; the proof of this is to be given when definite integrals are studied.

[4] In all this theory, attention is paid only to what happens when the function is taken to the limits of the convergence interval. The concept of uniform convergence does not appear in the syllabus.

[5] This rule may be assumed, but the convergence of the series to which it leads must be proved.

[6] The expansion of arc tan x, arc sin x, and of $\log(1-x)$ in series is obtained by integrating the differentiated functions. The exponential and binomial series are to be obtained from the equations $y' = y$ and $(1+x)y' = my$.

[7] L'Hopital's rule, except for the $\frac{0}{0}$ case, for a finite value of x, does not figure in the syllabus.

[8] These functions have only been introduced into the syllabus with a view to their use for calculations involving complex numbers, for trigonometry, and for the integration of linear differential equations with constant coefficients. The series which define them are convergent, whatever the value of x, so that this introduction does not require any development of knowledge about series involving complex variables, which is not included in the syllabus. It can be assumed that the rule for differentiation of integral series and the theorem of functions of functions apply to the case of a complex variable; or better the derivative of an imaginary function with a real variable may be enunciated, and the rule for differentiation of e^{mx} can be confirmed, for complex m.

[9] Maxima and minima of functions of several variables should not require any further treatment. The instructor shoule limit himself to showing that at any maximum or minimum, the partial derivatives become zero.

[10] The existence of implicit functions and of their derivatives is assumed.

[11] The pupils should have practice in direct calculations with differentials as with derivatives; they should make frequent use of such calculations, when the choice of independent variables is arbitrary, and should know how to make use of them for simple changes of variables and in calculations dealing with implicit functions. For the rest, only first order differential need be known.

General properties of algebraic equations. Number of roots of an equation.[1] Conditions for a number being a root of a given order of multiplicity.[2]

Relations between roots and coefficients. Calculation of an integral function with *symmetric roots, as a function of the coefficients of the equation.* Elimination of an unknown between two equations, by means of symmetrical functions.[3] Transformation of an equation by a rational substitution relating to a single root.

Special properties of equations with real coefficients. Conjugate imaginary roots. Method of finding the signs of the results of substituting two real numbers.[4]

Integrals. The area under the segment of a curve is the limit of the sum of the areas of the inscribed rectangles.[5] Definite integrals. Mean value of a function in an interval. Derivative of a definite integral considered as a function of its upper limit.[6]

Change of variable.[7] Integration by parts. Decomposition of rational fractions into simple parts. *Integration of rational differentials and those which become rational* by a simple change of variable.[8]

Application of the calculation of simple integrals to the measurement of plane areas, the calculation of volumes, the rectification of curves, the calculation of the area of a zone of revolution, the determination of centres of gravity, the calculation of moments of inertia and of kinetic moments.[9] Theorem of kinetic moments.

Differential equations.[10] Integration of differential equations of the first order: (a) where the variables *are directly separable;* (b) *where the equation is homogeneous* and linear.

Integration of linear second-order differential equations with constant coefficients and no second term; case where the second term is a polynomial or an exponential sum of the form $A\,e^{ax}$.[11]

General ideas about systems of linear differential equations with constant coefficients.

Numerical calculations. Use of tables of logarithms and the slide rule.

Approximate calculation of the root of an equation by Newton's method, by proportional parts, and by successive approximations.[12]

Approximate calculation of a definite integral by the *trapeze method.*

Analytic geometry

Preliminary ideas:

Vectors. Geometric sum. Scalar and vector product of two vectors. Moments.

---

[1] It is assumed that all equations, with real or imaginary coefficients, can have at least one real or imaginary root.

[2] Resolution into factors having roots of the same order of multiplicity does not figure in the syllabus.

[3] No attention is to be paid to the case where the coefficient of the term of highest order in x, in one of the equations, becomes zero, and the derivation of the common root by symmetrical functions is not to be given. For the rest, the pupils should have practice in making eliminations, in simple cases, by replacing the given equations by combinations of these equations having a lower order.

[4] As Rolle's theorem has been dealt with in the theory of functions, it is unnecessary to make a special application of it to integral algebraic equations. The reality of the roots of any equation $f(x) = 0$ is to be derived from a study of the variation of the function $y = f(x)$ and of the corresponding graph.

[5] The concept of area can be considered as primary, assuming that the area under a segment is the limit of the sum of the areas of the inscribed rectangles (whatever be the law of inscription) and the concept of definite integral can be deduced therefrom; or the reasoning can proceed in the opposite direction, assuming that the sum which serves for defining the integral has a unique limit for a continuous function and defining the area by the integral.

[6] It can be argued that the area represents the integral.

[7] The rule is to be deduced, for the definite integral as for the indefinite one, from the rule for the differentiation of the function of a function.

[8] What are involved are rational differentials in x and $\sqrt{ax^2 + bx + c}$ or in $\sin x$ and $\cos x$ or in e^x, ch x, sh x.

[9] None of these calculations should involve other than the calculation of a simple definite integral; multiple integrals are outside the syllabus. In each case the existence of the limit by which the magnitude under consideration is defined is assumed, or better still this magnitude is considered as a *primary quantity. It is to be presented as* the function of a variable; the differential is derived, and the function obtained again by integration. It can be assumed that the lengths of an arc and of its chord, the areas of a zone of revolution and of the corresponding frustrum of a cone are the equivalent infinitely small quantities.

[10] The teacher should restrict himself to the types explicitly indicated.

[11] It is to be assumed without proof that a family of solutions depending effectively on two variables must include all solutions.

[12] Methods of approximation will not be required for oral examinations. They can be justified by geometric considerations. The successive approximation method is to be given only for an equation of the form $y = \varphi(x)$ and it is to be supposed that the derivative $\varphi'(x)$ *is less than unity* in absolute value.

Plane geometry:

Rectangular co-ordinates. Transformation formulae. Distance between two points. Representation of a line by an equation. Order of an algebraic curve.

Straight lines. Representation of a straight line. Distance of a point from a straight line, angle between two straight lines.[1] Area of a triangle.

Homogeneous co-ordinates. Points at infinity and imaginary quantities. Anharmonic relationship of four collinear points and of four concurrent straight lines. Homography. Involution.

Circle.

Geometrical loci.

Curves whose equation can be solved for one of the co-ordinates. Tangent and normal to a point. Concavity, convexity, points of inflexion. Asymptotes. Application to the construction of curves.

Curves obtained by expressing the co-ordinates of the general point in terms of one parameter. Examples of constructions. Second order curves, and third order ones with a double point are unicursal.

Curves relating to an unsolved equation. Tangent and normal to a point. Tangents to the origin for algebraic curves for which this point is simple or multiple. Study of asymptotes for simple numerical examples, such as those of curves of the second and third orders. Simple examples of the plotting of curves.

Second order curves. Division into three kinds according to the nature of the infinity points; asymptotes. The different forms to which the equation of a conic can be reduced, using the method of decomposition into squares on numerical examples: corresponding geometrical forms.

Conditions for two points being conjugate with respect to a conic; polar of a point. Condition for conjugation of two straight lines; pole of a straight line.

Homography and involution on a conic.

Centres, diameters, conjugate directions, conjugate diameters.

Principal directions and symmetry axes;[2] reduced forms, calculation of their coefficients. Foci. Directrices. Study of foci and directrices on reduced equations.[3]

Study of curves of the second order by means of reduced equations; intersection with a straight line, condition for contact, simple problems on tangents;[4] ellipse considered as the projection of a circle; properties of a hyperbola relative to its asymptotes; properties of a parabola relative to its diameters, the subtangent and the sub-normal.

Polar co-ordinates. Their transformation into rectangular co-ordinates. Equations of the straight line, circle, and of a conic whose pole is a focus. Tangents, asymptotes; application to the construction of curves whose solution is given in terms of a radius vector.

Envelopes. Description of a curve by the general equation of its tangent. Development of a plane curve; curvature.

Solid geometry:

Rectangular co-ordinates. Representation of a surface by an equation, and of a line by a system of two equations. Order of an algebraic surface and curve. Parametric representation of curves and surfaces.

Straight line and plane. Representation. Simple problems about intersections.

Sphere. Equation. Tangent plane at a point.

Surfaces. Tangent plane. Normal. Examples of surfaces developed by simple methods of generation: cylinders, cones, surfaces of revolution, particularly paraboloid of revolution.

Second order surfaces. Classification by the nature of the infinite points. Study of the ellipsoid and the hyperboloid, in rectangular co-ordinates and related to the centres. Tangent planes. Plane sections.

Space curves. Tangent. Osculating plane, curvature. Application to circular helix.

---

[1] Problems of angles and distances, in plane and solid geometry, are only to be treated within the framework of rectangular co-ordinates.

[2] In rectangular co-ordinates.

[3] In rectangular co-ordinates.

[4] The problem of normals coming from a point (Apollonius' hyperbola) and the construction of a conic with a centre of which the two conjugate diameters are given, does not enter into the syllabus.

Mechanics

Kinematics:

Kinematics of a point. Rectilinear movement; velocity, acceleration, uniformly varying movement, simple vibrators.

Curvilinear movement. Vector, velocity, hodograph. Acceleration vector; tangential and normal accelerations.

Movement relative to rectangular or oblique axes, or to cylindrical co-ordinates.

Kinematics of an invariant system. Translation. Rotation around a fixed axis. Helicoidal movement.

Change of reference frame. Composition of velocities. Composition of accelerations when the reference frame undergoes a translatory movement.

Statics and dynamics:[1]

Material point. Field of force. Mass. Principle of inertia. Equality of action and reaction. Relation between mass and weight. Work. Units. Composition of forces acting on a material point.

Statics of a point. Equilibrium of a free material point, of a material point forced to remain on a fixed curve and a fixed surface, with and without friction.

Statics of systems. Proof that there are six necessary conditions for equilibrium independent of the internal forces. These six conditions are sufficient for invariant systems.[2] Special cases.

Equivalence of two systems of forces applied to a solid body. Application to the reduction of systems of forces. Composition of couples. Centres of parallel forces, centre of gravity.

Equilibrium of an invariant solid which is not free. Case of a fixed point, a fixed axis with and without slip along the axis, of one, two, or three points of contact with a fixed plane. Reactions.

Simple machines.[3] Lever, fixed pulley, Quintenz balance, windlass, movable pulley, systems of pulleys. Confirm that, in these machines, the algebraic sum of the virtual work done by the force and the resistance (load) is zero, for a small displacement around the position of equilibrium.

Dynamics of a point. Theorem of live force. Kinetic and potential energies of a point in a field of force.[4]

Free point. Movement of a point under the action of a force constant in direction and magnitude, and under that of an attractive force coming from a fixed centre:[5] (a) proportional to the distance; (b) varying inversely with the square of the distance.

Homogeneity. Dimensions of a velocity, an acceleration, a force, a work, and a live force (kinetic energy).

Physics

The first question in physics: physical magnitudes. Units:

Units and standards. Fundamental units and derived mechanical units: dimensions. Absolute and practical units. C.G.S., M.T.S., M.K.S., systems.

Measurement of magnitudes.

Approximation in measurements: systematic and random errors, relative and absolute errors. Calculation of errors.[6]

Heat. Measurement of temperature. Standard thermometer, mercury thermometer.[7] Definition and measurement of a quantity of heat. Method of mixtures,

[1] No difficulty with be raised about the principles of mechanics. It is to be assumed that the force applied to a material point is geometrically equal to the product of the mass at the point and the acceleration impressed on it, and if several forces act at a point, the acceleration they produce is the geometric sum of the accelerations which they would each produce if acting separately.

[2] This second proposition may be assumed.

[3] Friction not to be taken into account.

[4] Assuming this field to be derived from a function of the force.

[5] In dealing with movement produced by central forces, attention is to be restricted to the two laws indicated; this naturally leads to proving the theorem of areas.

[6] Examples of calculations of errors are to be based upon experimental results obtained during the course.

[7] Corrections for internal and external pressure are not required.

practical corrections. General results of measurements of the specific heat of solids, liquids, and gases, at constant pressure.
Laws of compression and expansion of gases. Boyle's and Charles' laws as first approximations; results of Amagat's experiments; isotherms.
Change of state. Enunciation of the phase rule and the laws for displacement of equilibrium.
Vaporization, liquefaction. Andrews curves. Critical point.
Ebullition of a pure substance, and of a mixture of two liquids.
Heat of vaporization; Regnault's equation for water.[1]
Fusion and solidification. Heat of fusion. Dissolution; eutectic point.
Effect of solute on the melting and boiling points; Raoult's law.

The second question of physics: oscillations, vibrations, and waves:
Generalities on oscillations and vibratory movements.
Main characteristics. Laws and their algebraic representation. Phase. Phase difference. Natural vibrations. Forced vibrations. Resonance.
Examples of vibratory motion: pendulum, vibrating wires, vibrating reeds, ideas about elastic waves in homogeneous isotropic media. Sinusoidal oscillations. Fresnel representation. Propagation. Wavelength.
Composition of vibratory movements. Principle of superposition of small movements. Beats and interference. Effect of phase difference and velocity difference. Conditions for interference. Composition of two simple periodic motions, in orthogonal directions. Weakly damped movement.
Sound waves.
Radiation of energy from a source of sound in an elastic medium. Sound sources. Speed of sound. Sound interferences.
Light waves.
Character. Generation. Propagation. Measurement of velocity. Frequency and wavelength. Monochromatic waves. Polarization. Interference. Fresnel conditions. Experiments on interference with light. Coloured rings. Gratings.
Electromagnetic waves.
Character. The gamut of electromagnetic waves: ordinary (radio), infra-red, visible, ultra-violet, X-rays, γ-rays.
Production of ordinary electromagnetic waves: phenomenon of radiation. Velocity and wavelength. Polarization. Hertz' experiments. Oscillators and resonators. Selection principle. Interference of electromagnetic waves. Application to telegraphy and radio.

Optics:
Descartes laws. Optical path; Fermat's theorem. Malus' theorem; wave surfaces.
Ray-bundles of small aperture; their general structure: focal lines.
Plane mirror. Spherical mirrors, plane dioptre, sheet with plane parallel faces, in the case of Gauss' approximation. Prism: minimum deviation. Spherical dioptre and centred systems in the case of Gauss' approximation.
Experimental determination of foci and of the principal planes of a centred system.
Generalities about optical instruments,[2] power, magnification, resolving power, field of view; definition.
Simple and compound lenses. Microscope. Astronomical telescope. Terrestrial telescopes; long-range telescope, prism telescope (field glasses), Galileo's telescope (opera glasses), telescope. Photographic objective.

Chemistry

General chemistry

Physical phenomena. Various states of matter. Crystallization. Dimorphism. Polymorphism. Isomorphism.
Chemical phenomena. Pure substances. Elements and compounds.

[1] Results, without descriptions of experiments.
[2] The student is not expected to show knowledge of the details of construction, but only of the comparative virtues of the different instruments and the qualities that are required of each of them.

Laws which govern combinations. Gravimetric and volumetric laws.
Atomic notation. Molecular weights. Atomic weights. Their selection. Avogadro's and Ampere's laws; Raoult's law, law of specific heats, law of isomorphism. Valency. Radicals. Heat effects accompanying chemical reactions; rule of the initial and final states. Experimental study of some chemical equilibria. Dissociations. Phase rule. Law of displacement of equilibrium. Law of mass action.
Catalysis.
General character of various classes of chemical substances: acids, anhydrides, bases, *basic oxides, salts.*
Very elementary ideas about ionic theory. Heat of formation of salts. Berthollet's rules.

Non-metals[1]

Hydrogen.
Chlorine. Hydrochloric acid. Bleaching powders.
Oxygen. Ozone. Water. Metallic oxides. Hydrogen peroxide.
Sulphur. Sulphuric acid. Sulphur trioxide. Hydrogen sulphide.
Nitrogen. Ammonia. Nitric acid.
Phosphorus. Phosphoric acid.
Carbon. Carbon monoxide. Carbon dioxide.
Silicon. Silica.

Metals

Structure of metals and alloys. Phase diagrams. Micrography and macrography.
Physical properties. Thermal analysis. Expansion and density, electrical and thermal conductivity, magnetism, thermo-electricity, solution potentials, crystalline diffraction and corrosion of metals and alloys.
Production[2] and main properties of the following metals (with simple enumeration of their principal alloys): iron, copper, lead, zinc, tin, nickel, cobalt, aluminium, sodium, potassium, calcium.

General Electricity

Electrostatics

Electrical charges. Coulomb's law. Electrostatic field. Lines of force. Potential. Equipotential surfaces. Flux. Gauss' theorem. Conductors and insulators. Conditions of equilibrium on a conductor. Coulomb's theorem. Induction. Hollow conductors. Electrical screens. Faraday cage. Capacities and induction coefficients. Capacities. Effect of a dielectric. Electrostatic pressure. Electrostatic forces between conductors. Electrostatic energy of a condenser. Localization between the plates. Electrostatic machines (elementary ideas).

Magnetism

Permanent and temporary magnets. Magnetic masses. Coulomb's laws. Magnetic field. Lines of force. Magnetic flux. Magnetic moment. Action of a field on a magnet. Magnetic shells. Intensity of magnetization. Field inside a magnet. Magnetic induction. Lines of induction. Magnetic flux.
The earth's magnetic field. Horizontal and vertical components.

Electric currents

Generation of current. Electromotive force. General properties of electric current. Current strength. Ohm's law; resistance and resistivity. Current vector. Current density. Extension of Ohm's law to a homogeneous conducting medium. Conserva-

[1] In the study of non-metals, physical and chemical properties are to be dealt with briefly with no reference whatever to industrial manufacturing methods.
[2] In the preparation of the various metals, metallurgy is summarized a great deal, and the only things to be dwelt on are the economic aspects, the phases (of metallurgy) involving the use of electricity, and the refining of metals used as conductors.

tion of electricity. Kirchoff's law. Joule's law. Electrolysis. Faraday's laws. Polarization of electrodes. Accumulators. Volta effect. Peltier effect. Thermo-electric electromotive force. Thomson effect. Voltaic cells. Depolarization. Various kinds of batteries. Series and parallel grouping. Thermo-electric piles.

Electromagnetism and electrodynamics

Magnetic field of a current. Ampere's theorem. Biot and Laplace's equation.
Action of a field on a current element and on a closed circuit. Laplace force.
Induced currents. Lenz' laws. Induced electromotive force. Faraday's law. Mutual induction. Self-induction. Induction coil. Correlation of induction phenomena with those of electromagnetism.
Paramagnetism. Diamagnetism. Induced magnetization. Ferromagnetism. Hysteresis. Dielectrics. Polarization. Electrical induction. Lines of induction. Electric flux. Ideal and real dielectrics. Hysteresis.
Alternating currents. Representation of sinusoidal quantities by vectors and by complex numbers. Mean values. Effective values. Power.
Ohm's law. Impedance.
Alternating magnetic fields. Induced currents.
Polyphase currents. Rotating magnetic fields induced by such currents. Action of a rotating field on a magnet and on a closed circuit.

Brief review of concepts in electronics

Electrons and ions. Thermionic emission. Vacuum valves. Gas-filled valves (diodes and triodes). Industrial applications.

Brief review of radiofrequency phenomena

Radiation. Aerials. Production and reception of electromagnetic waves. Wave propagation. Applications.

Industrial electrical machines

Magnetic circuits: general laws, circuits in series and parallel. Magnetic leakage. Ideas about electromagnets.

Direct current:
Direct current dynamos. Principle of operation of a bipolar dynamo with separate excitation; determination of the electromotive force and of the opposing torque; brief treatment of the armature reaction. Use of the dynamo; measurement of the opposing torque. Characteristics of series and parallel winding of the exciting field magnets.
Direct current motors. Reversibility of the direct current dynamo having separate excitation. Operation as a motor. Comparison of the directions of rotation as a motor and as a generator. Expression for the electromotive force and the motor torque. Starting.
Characteristics of series and shunt excitation.

Alternating current:
Coils with iron cores.
Transformers.
Machines with rotating fields: principle of operation of single and poly-phase alternators; determination of the induced electromotive force on no load; brief description of armature reaction.
Principle of operation of three-phase synchronous motors.
Principle of operation of three-phase asynchronous motors.

Electrical Measurements

Measurement of resistance. Application of Ohm's law.
Comparison method. Theory of the Wheatstone bridge and its application to measurement of resistance.

Measurement of potentials. Measurement of small electromotive forces and of potential differences. Principle of the opposition method. Various arrangements. Principle of potentiometers.
Electrometers: principle of the quadrant electrometer.
Possibility of using this apparatus for measuring capacitances by the old methods of comparison and charge distribution.
Galvanometers. Principle of the moving coil galvanometer. Principle of the ballistic galvanometer. Possibilities of using the apparatus for measuring capacitances (by repeated discharging).
Principle of the moving magnet galvanometer. Moving coil volt- and ammeters.
Measurement of capacitance: de Sauty bridge method, using battery or accumulator.
Magnetic quantities; absolute measurement of magnetic moment and field; Gauss' method.
Measurement of the intensity of a magnetic field in an air-gap using a search coil connected to a ballistic galvanometer.
Electrodynamometers. Various. Principle of wattmeters (use of these on alternating current is not required).
Characteristics of vacuum valves (diodes and triodes), of phanatrons and thyratrons; form of characteristic under static conditions. Measurement of the internal resistance and the slope for vacuum valves.

Engineering Drawing

Sketches of sub-assemblies, made in accordance with the design of the whole unit, with all the information necessary to enable these sub-assemblies to be reproduced.

Laboratory Notebooks

The laboratory notebooks, which must be presented by the candidates to the examiners in physics, general electricity, and electrical measurements, must contain accounts of at least four experiments in general physics and twelve in electricity, selected from the following list:

General physics:
- Torsion pendulum; torsion constant. Moment of inertia.
- Measurement of vapour densities by Victor Meyer's method.
- Measurement of the heat of vaporization of a liquid.
- Study of divergent and convergent lenses.
- Goniometric measurement of the angles of a triangular prism.
- Photometric measurement by visual photometry.
- Photometric measurements by photo-electric photometry.
- Manipulation of vibrating wires, reeds, elastic waves on liquid surfaces. Interference phenomena on such surfaces, obtained from two synchronous point sources, with variable phase difference.
- Measurement of the velocity of sound by resonance.
- Measurement of wavelength by Young's slits and with a grating.

Electricity:
- Measurement of resistance by Wheatstone's bridge.
- Measurement of the power dissipated on direct current with a wattmeter.
- Measurement of power dissipation on alternating current with ammeter and voltmeter.
- Temperature of a field coil on constant voltage.
- Calibration of a fluxmeter.
- Calibration of an ammeter by electrolysis.
- Study of a coil galvanometer. Determination of the constants: moment of inertia, torsion constant, critical resistance.
- Measurement of resistance by ammeter and voltmeter. Resistance and consumption of an incandescent lamp as a function of the current.
- Study of a moving coil ballistic galvanometer.
- Study of capacities: charge, residual charge, insulation resistance.

Coil galvanometer. Measurement of its resistance. Conversion to ammeter and voltmeter.
Measurement of a high resistance by comparison.
Measurement of a high resistance by loss of charge.
Comparison of capacities by the de Sauty bridge method.
Plotting a hysteresis cycle by Ewing's method.
Measurement of induction and permeability by the ring method.
Measurement of electromotive forces by opposition; calibration of an ammeter and *a voltmeter.*
Measurement of a mutual inductance with a fluxmeter.
Alternating current; capacitance and self-inductance in series.
Magnetic characteristic of a dynamo. Measurement with a fluxmeter.
Flux in an induction coil and its variation with position.
Study of a dynamo with separate excitation.
Study of a direct current motor.
Study of a transformer.
Measurement of M/H.
Plotting of the static characteristics of a diode and a triode.
Triode oscillator. Excitation of oscillations. Measurement of the frequency. Resonance.

The candidates who have followed the course for certificate (degree) in general physics are not restricted to the presentation of a special notebook. They have only to present to the examiners the laboratory notebook for the degree.

Admission by Certificates

Engineers who already hold diplomas from certain *Grandes Écoles* (higher professional schools), such as officers and engineers designated by the various French ministries, and a certain number of *licenciés-ès-sciences* (graduates) holding the proper diplomas are admitted by certificate each year (one hundred altogether), which brings to 250 the recruitment for the whole college (both divisions).

Duration of Studies

This is normally two years, for both divisions, completed by a period in industry during the vacation between the first and second years. Nevertheless certain graduate engineers, capable of being admitted by certificate, and having obtained in the course of their previous studies marks and positioning considered extremely satisfactory, can be authorized, on request, to benefit by "special conditions" which permit them to obtain the leaving diploma at the end of fourteen months of study (this applies only to the division of electricity).

TEACHING PROGRAMME

Theory

This comprises about 300 lectures during the year, of one and a quarter hours each, at the rate of two per morning, given in four lecture theatres (one per annual intake for each of the two divisions) capable of seating 300, 200, 120 and 100 respectively, and with equipment for projection of films and lantern slides. The equipment necessary for illustrating the various courses will be found under the section "Demonstration apparatus".

Table 1 indicates, for the two years of study, the teaching programme, to which are to be added *oral exercises*, individual oral examinations, sessional and final examinations, written exercises, and projects.

Practical Work

This consists of laboratory work, lasting for a minimum of four hours, carried out in the afternoon by groups of two or four students, who write up in a notebook all the experimental results obtained during these periods of practical work.

These experiments or tests (checked by separate examination, and by sessional and final examinations in which the students have to repeat, entirely on their own, one experiment drawn by lot) involve electrical measurements, tests on machines, and work on winding for the division of electricity, and on electrical measurements, radio-frequency measurements and tests on machines for the division of radio-electricity and electronics.

Table 1. Timetable for lectures and practical work at the École Supérieure d'Électricité (1951).

Subject	Hours during the two years: Lectures	Hours during the two years: Practical work
Teaching Common to both Divisions (without practical work)		
Mathematical and physical sciences		
Mathematical complements	30	
Statistical methods used in physics	5	
Corpuscules, waves, and wave mechanics	6	
Economic and social sciences		
Scientific organization of work	5	
The engineer in business	5	
Industrial accounting	4	
Industrial psychology	2½	
Teaching Special to the Division of Electricity		
Physical sciences		
Electrical discharge in gases, vacuum tubes, cathode- and X-rays	6	—
Electro-acoustics	10	12
Applied thermodynamics	30	—

Subject	Hours during the two years: Lectures	Practical work
Mechanics and strength of materials complements	19	4
Luminous sources and photometry, indoor and outdoor lighting installations	15	12
Theoretical electrotechnics		
Introduction to electrotechnics	25	—
Electrotechnics	75	—
Electrical measurements	62	260
Electrical machines		
Introduction to the study of electromagnetic machines	30	—
Winding of electrical machines	7½	24
Design and construction of static electrical machines	15	—
Design and construction of rotary electrical machines (electrical part)	30	—
Design and construction of rotary electrical machines (mechanical part)	15	—
L.T. equipment for electrical machines	15	—
Tests on electrical machines and practical study of their properties	40	184
Rectifiers	7½	4
Servo-mechanisms	19	12
Power stations		
Thermal equipment of power stations	16	—
Distribution lines and networks		
Electrical cables and insulated conductors	7½	24 (both)
Design and construction of overhead lines	7½	
Transmission networks	10	—
Distribution networks	10	—
Electrical equipment of networks (power stations, main and subsidiary substations, lines, cables, H.T. equipment)	31	—
Control	4	—
Hydraulics		
Applied hydraulics	22½	—
Hydraulic dams	4	—
Telecommunications		
Telecommunications by wire	10	—
Telecommunications on power lines	7½	—
Radio-electricity and electronics		
Wireless communication	19	—
Elements of electronics	19	24
Amplifying valves	7½	—
Applications of electricity		
Electrical traction	22½	—
Mechanical applications of electricity	15	—
Electrochemistry, electrical furnaces, electrometallurgy	19	—
Thermo-industrial applications of electricity	15	—
Domestic applications of electricity	7½	—
Agricultural applications of electricity	4	—
Economic sciences and legislation		
Commercial exploitation of power and tariff fixing	6	—
Juridical and legislative questions	6	—

Teaching Special to the Division of Radio-electricity and Electronics

Subject	Lectures	Practical work
Electrical theory		
Electrical theory, electromagnetic waves	38	—
Propagation of electromagnetic waves	19	—
Electrical circuits, networks, and filters	50	40
Theory and technique of V.H.F.	31	20
Basic notions of electronics	19	8
Measurements in radiotechnics	57	120

Subject	Hours during the two years: Lectures	Practical work
Transmission and reception		
Transmission, design and construction of transmitters	31	88
Reception, design and construction of receivers	31	28
Radio broadcasting	10	—
Television	19	—
Lines and aerials	38	24
Radiolocation and radionavigation	19	—
Design and construction of radar equipment	12	—
Electron tubes and general equipment in the radio-electrical industry		
Present trends in the radio industry	2½	—
Equipment	31	—
Physical study and construction of electronic valves, vacuum techniques	25	32
Operation and use of vacuum valves	31	—
Communications		
Theory of the transmission of information	12	—
Communication by wire	15	—
Organization, use and regulation of radio-communications	15	—
The radio-communications used by the public services	19	—
Various applications		
Application of piezo-electricity to transmission	10	—
Application of radio-electricity in the army	4	—
Application of radio-electricity in the navy	4	—
Application of radio-electricity in aviation	4	—
Electrotechnics and miscellaneous		
Applied electrotechnics	15	—
Electrical measurements	22½	72
Tests on electrical machines	19	72
Servo-mechanisms	19	8
Electro-acoustics	10	—
Telecommunications on power transmission lines	7½	—

Total Duration of Lectures and Practical Work during the Two Years of Study:

Division of electricity	749	560
Division of radio-electricity and electronics	697	506

INVENTORY OF INSTRUCTIONAL MATERIAL AND CONTENTS OF COURSES

COURSE CONTENTS COMMON TO BOTH DIVISIONS AND NOT GIVING RISE TO ANY PRACTICAL WORK

(given only as an example to facilitate the use of the inventories)

Mathematical and Physical Sciences

Mathematical Complements

These complements contain the essentials of those branches of mathematics the knowledge of, and facility in, which are essential to the engineer, with very numerous applications to the field of electrotechnics and radio-technology.

Complex quantities. Functions of complex variables. Singular points. Integration by the method of residues. Conformal transformations. Fourier series and integral. Spectra of frequencies. Vector calculus. Differential operations on vectors. Vectorial integrals. Ostrogradsky's theorem, Green's and Stokes' equations. Matrix calculus. Operations on matrices. Generalization of space to n dimensions, and to complex space. Tensor calculus. Co-variance and contra-variance. Symmetry and anti-symmetry. Operations on tensors. Criterion of tensor character. Differential and partial differential equations in rectangular and curvilinear co-ordinates. Certain common functions: integral sine and cosine, error function, factorial function, Bessel functions, Legendre polynomials. Heaviside's symbolic calculus. Principles of probability calculus; survey of probability functions.

Statistical Methods used in Physics

Statistical laws. Classical statistics (Boltzmann, Maxwell, Gibbs) and recent statistics (Bose-Einstein, Fermi-Dirac). Some important applications: calculation of statistical weights and of entropy; degrees of freedom, summation over all possible energy states; calculation of the vibrational component of the specific heat; fluctuations; measurement of the Avogadro number. Electronic theory of metals.

Corpuscules, Waves, and Wave Mechanics

Discontinuous structure of electricity. Theory of electrons, its successes and failures. The Planck quantum. General survey of theories of light and radiation. Waves and photons. Wave mechanics and electron diffraction. Applications of wave mechanics; its physical interpretation. The Heisenberg uncertainty principle.

Economic and Social Sciences

Scientific Organization of Work

Organization of work in the past. Present trends. National and international rationalization. Technical preparation of work. Bureau of studies and bureau of methods. Analysis of work. Time study, modern methods of chronometric study of work. Process operation sheets, instructional cards. The administrative preparation of work: orders, supply of materials, starting up the process, progressing. Methods for calculating manufacturing costs: examples.

The Engineer in Business

Advice for after-college training: personal training, professional training. Study of the principal problems in industry: quality control, invention, manufacturing costs, administration, delays, commercial and social problems, management.

Industrial Accounting

The clear appreciation of the overall situation. Statement of the credit, debit, and net situation. Profits and losses. Presentation of a balance. Reality and fictitiousness of statements. The various parts of the balance. Accounts, interaction of accounts. Technical accounts and records. Profit and loss account.

Industrial Psychology

Classification of applied psychology: individual, collective, and inter-individual. Industrial psychology. General study of work and methods of examination. Various examples of tests used.

APPARATUS WHICH CAN BE USED FOR ALL COURSES

Quantity	Item and characteristics	Total cost in dollars
	Demonstration Apparatus	
1	Sound film projector, 35 mm, with sound head, rectifier 110 V, 50 c/s	1,700
	Essential ancillary apparatus: amplifier, loudspeaker, group filter for loudspeaker, pick-up and turntable	1,300
1	Sound film projector, for 16 mm sound track, complete	600
4	Screens	60
2	Epidiascopes, small size, 110 or 220 V	368
4	Projection lanterns, for lantern slides	712
1	Cathode ray oscillograph, projection pattern	720
	Total	5,460

APPARATUS FOR SUPPLYING ELECTRIC POWER

Quantity	Item and characteristics	Total cost in dollars
1	Transformer station: 4 transformers, 10,500/200/115 V (1 for 200 kVA, 2 for 100 kVA, 1 for 25 kVA) with natural oil cooling, complete with switchboards (mechanism for setting the H.T. circuit breaker, L.T. isolator, ammeter and voltmeters); 1 switchboard carrying indicators and recording wattmeters, circuit breakers controlling the distribution circuits taken from the busbars fed by the transformers	18,500
	Electrical Supply Substation for Electrical Measurements (see p. 36)	
1	Motor alternator set, for supplying the workshops, comprising: 1 three-phase synchronous induction motor, 35 H.P., 200 V; 1 three-phase alternator, 25 kVA, 1 starter at the end of the shaft	1,600
	Carried forward	20,100

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	20,100
1	Motor generator set for charging two banks of accumulators, 400 Ah, comprising: 1 asynchronous motor, three-phase, 24 H.P., 200 V; 1 DLCL generator, with shunt excitation, 70 A, 100-160 V	1,750
1	Booster set for charging 1 bank of accumulators, 40 Ah, comprising: 1 three-phase asynchronous motor, 2 H.P., 200 V; 1 D.C. generator, shunt-wound, 13 A, 4-70 V	540
1	Tungar rectifier, 200 V, 10 A, rectifying to 7.5-30 V	160
1	Distribution switchboard (7 panels), designed to centralize all the equipment for controlling, starting, and protecting the various machines mentioned above, means for controlling the charging rate on batteries, the inputs from the transformer bank and the outputs to the busbars for feeding the electrical measurements section	2,400
1	Motor alternator set, for producing a voltage free from harmonics, comprising: 1 three-phase commutator motor, 22 H.P., 200 V, speed variation by displacement of brushes; 1 single-phase alternator, 5-12 kVA, 100-200 V	1,900
1	Motor alternator set, operating at audio frequency, comprising: 1 D.C. motor with shunt excitation, 2 H.P., 120 V; 1 alternator capable of producing a frequency between 500 and 1100 c/s	800
1	Motor generator for calibration of electric meters and wattmeters, comprising: 1 D.C. motor with two collectors, 2 H.P., 120 V; 2 alternators with polygonal windings, and arranged for phase shifting stators, one with an output of 30 A at 10 V, the other with an output of 4 A, 200 V, single-, two- or three-phase	1,800
1	Motor alternator set ('harmonic'), comprising: 1 D.C. motor with shunt excitation, 3 H.P., 120 V; 1 main alternator, single-phase, 50 c/s; 3 alternators with displaceable stators contained in the same housing and producing respectively the 3rd, 5th and 7th harmonics of the main alternator	1,800
2	Batteries of lead accumulators (electrical measurements section) charged by the corresponding substation, each one consisting of 64 cells of 400 Ah each (for a 10 h discharge rate)	4,800
1	Battery of lead accumulators (electrical measurements section) comprising 90 cells each of 40 Ah (for a 10 h discharge rate)	1,600

Electrical Supply Substation for the Electrical Machines Section (see p. 46)

Quantity	Item and characteristics	Total cost in dollars
3	D.C. motor generators, for charging 2 batteries of accumulators always in series, at 60 V (using 2 of these sets under special conditions: generators in floating connexion with batteries), comprising: 3 three-phase synchronous motors, 54 kVA, 200 V; 3 D.C. generators with separate excitation, 700 A, 60 V, with excitation current supplied by a special converter set comprising 1 asynchronous motor of 18 H.P., 2 shunt-wound generators, 80 A, 60 V	18,000
3	Motor generators with full automatic control (by on load tap changer for single-phase and two-phase and by power factor regulator for three-phase), comprising: 3 synchronous three-phase motors, 54 kVA, 200 V, coupled with: 1 single-phase alternator, 35 kVA, 115 V; 1 two-phase alternator, 54 kVA, 115 V; 1 three-phase alternator, 54 kVA, 115 V; 2 exciters per set (18 A, 65 V)	14,000
1	Switchboard for centralizing the equipment for starting, controlling, and protecting the converter sets (in particular an auto-transformer with 1 : 2 ratio, and an inductance for starting asynchronously under reduced voltage, the 6 synchronous motors mentioned above and output circuits each with a cutout for maximum current and minimum voltage	8,800
	Carried forward	78,450

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	78,450
1	Generating set, independent, comprising: 1 diesel engine of 140 H.P., coupled with: 1 three-phase alternator, 100 kVA, 200 V, with thyratron voltage control, acting as an emergency stand-by service for the various sections of the school, or 1 single-phase alternator, 100 kVA, 115 V (feeding the switch-testing laboratory)	22,500
2	Batteries of lead accumulators (electrical machines section) charged by the corresponding substation and always connected in series, each consisting of 30 units each of 1000 Ah (for a 10 h discharge rate)	9,600
	Total	110,550

INVENTORY OF EQUIPMENT USED BY THE DIVISION OF ELECTRICITY

PHYSICAL SCIENCES

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

Electrical Discharge in Gases, Vacuum Tubes, Cathode- and X-rays

Vacuum technique.
Static characteristics of valves: pure electronic discharge and ionic discharge, various kinds of valves.
Cathode rays: general properties, magnetic and electric deflection, secondary emission, miscellaneous applications. Cosmic rays.
X-rays: emission and absorption spectra, photo-electric effect, Compton effect; dispersion, measurement of wavelength and intensity of X-rays, various kinds of tubes.

Electro-acoustics

Electromagnetic apparatus. Electrical and mechanical impedance. Kennelly's circle theory: application to the determination of the efficiency of loudspeakers and microphones.
Propagation of plane sound waves. Speed of propagation. Acoustic impedance. Transmitted power. Physiological quality of sound. Physical and physiological intensity of sound. Reference level. Fletcher's curves.
General equations for the reflection and refraction of plane sound waves.
Equations for passage from one medium to another. Resonant pipes.
Spherical waves. Webster's equation. Power radiated. Diffraction.
Study of sound radiation from a loudspeaker. Sound radiation from the pulsating sphere and the vibrating piston. Kinetic impedance of a loudspeaker. Directing effect of the membrane. Exponential horn, conical horn. Resonators and acoustic filters. Role of the compression chamber.
Classification of microphones. Microphones sensitive to pressure and to pressure gradients; microphones with preponderating mass, elasticity, and strength. Efficiency of a microphone. Background noise. Microphones of various types: condenser, piezo-electric, electromagnetic tape, carbon. Measurement of acoustic impedance: Stewart's and Flanders' methods.

Applied Thermodynamics

Brief reference to the first and second laws of thermodynamics. Their applications to change of state and to heat engines, with numerous examples. Elements of fluid mechanics. Numerical date for steam. Entropy diagrams: their use. The nozzle: its methods of operation.

Steam turbines

Laval turbine. Multi-stage turbine. Simplified design. Double head wheel. Project. Reaction turbine, combined turbine. High- and low-power turbines. Special turbines: regenerative, back-pressure, by-pass, naval.
Condensation of steam, coolants.

Heat engines and reciprocating motion

Single-cylinder steam engines. Diagram. Losses. Compound engines. Distribution, control. Special engines.
Internal combustion engines: 2- and 4-stroke. Petrol engines. Detonation. Octane number. Carburation and injection. Power output and equilibration of multi-cylinder engines. Producer gas engines. Details of construction. Scavenging and supercharging.
Diesel engines. Pneumatic and mechanical injection. Two-stage engines. Scavenging and super-charging. Recovery of motive power from the exhaust gases. High speed engines having small cylinders.

Turbo-compressors and gas turbines

Centrifugal and axial turbo-compressors. Theory. Development. Gas turbines: the different cycles. Application of the gas turbine to aviation; turbo-jet and turbo-propeller engines.

Mechanics and Strength of Materials Complements

Generalities on elementary dynamics of systems: fundamental theorems.
Movement of a solid around a fixed axis.
Collision and impact.
Sliding and rolling friction.
Basic concepts in the theory of elasticity.
Generalities on strength of materials. General theorems.
Stresses on a transverse section of a long beam.
Strains and deformations produced by single-type stresses: simple extension, simple compression, bending moment, breaking load, torsional moment.
Strains and deformations produced by combined stresses on long beams.
Calculation of hyperstatic structures.
Stresses on a rotating body, strains and deformations.
Characteristics of materials, strength criteria at the elastic limit and at rupture.
Mechanical properties of the soil; calculations for foundations, angle of rest of earth.
Calculations for buildings. Reinforced concrete.

Luminous Sources and Photometry, Indoor and Outdoor Lighting Installations

General considerations on radiations. Laws of thermal radiation.
Definition of photometric units. Photometric standards.
Incandescent luminous sources. Characteristics and efficiency factors of normal lamps. Design and manufacture of filaments.
Discharges in gases and metallic vapours. Application to lighting. Various types of discharge lamp: H.T. and L.T. Fluorescent lamps. Carbon arcs. A.C. arcs.
Visual photometry: various types of photometers. Measurements of luminous intensity and flux, of absorption, transmission, and reflection. Photometry of coloured sources. Spectrometry, colorimetry. Physical photometry. Photographic photometry.
Lighting of interiors. Use of factor method. Decision as to layout: economic factor. Direct calculations and checks on lighting. Lighting by high-power sources. Lighting of public highways. Distribution of luminous flux. Various methods of calculating the average illumination. Contrast in lighting. Measurements made directly on public highways. Remote control.
Lighting of large spaces; aerodromes and sports stadiums.
Public lighting circuits and the lighting of large spaces. Parallel distribution at H.T. and series distribution at L.T.

PRACTICAL WORK

Electro-acoustics

Plotting the impedance curve of a telephone or of a loudspeaker. Sound intensity, analysis of complex sounds, measurements of noise. Directivity of a microphone and of a loudspeaker. Time of reverberation.

Strength of Materials

Measurements of mechanical deformations by electrical methods.
Static and dynamic extensometers.

Luminous Sources and Photometry

Measurement of the luminous intensity of a source (lamp).
Measurements of luminous flux and illumination.
Study of the characteristics of thermocouples.
Measurement and control of temperature.
Plotting the characteristics of a photo-electric cell.
Study of a luminescent tube: power factor, efficiency, harmonics.

EQUIPMENT (only that directly concerned with electrical measurements is given here; the ancillaries are mentioned in the section on electrical measurements, p. 36).

Quantity	Item and characteristics	Total cost in dollars
4	Loudspeakers (energized)	13
4	Loudspeakers (permanent magnet)	16
3	Lumenmeters	270
6	Luxmeters of various types	420
8	Photo-electric cells, with diaphragms	330
1	Photometry room (white-painted walls, indirect lighting variable by auto-transformers) comprising 6 fully equipped photometric benches, each comprising 4 "current" circuits, in parallel, and 4 "voltage" circuits, independent, connected to the general distributors of the main laboratory (see electrical measurements, p. 36)	2,100
	Total	3,149

THEORETICAL ELECTROTECHNICS

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

Introduction to Electrotechnics

Fundamental laws of electrostatics. Electrical field and potential. Electrical screens and images. Dielectrics in static electrical field. Capacitances and capacitors, extended to the case of *n* plates, capacity of lines and poly-phase cables.
Fundamental laws of magnetism. Magnetic field and induction. Permanent and temporary magnets. Bar magnets. Vector potential of the induction field.
Fundamental laws of electrodynamics. Electromotive force and electric current. Principles of superposition. Transformation of networks.
Fundamental laws of electromagnetism. Magnetic field of a current. Action of magnetic fields on currents.
Fundamental laws of induction. Induced e.m.f. in a movable conductor placed in a variable magnetic field.
Propagation of an electromagnetic field in an insulating and in a conducting medium.

Electrodynamic energy of moving circuits in a fixed magnetic field, and of systems of currents in fixed circuits.
General properties of circuits, and calculation of their coefficients of mutual and self-induction.
General study of *alternating currents* by the algebraic method, the vectorial method and by the use of complex quantities. Power with sinusoidal alternating current, resonance.
Generalities about non-sinusoidal A.C.
Distribution of longitudinal A.C. in a cylinder, and in a very long bar.
Foucault currents in cylindrical conductors and metallic sheets, produced by an alternating sinusoidal field.
Resistance and inductance at high frequencies.

Electrotechnics

The magnetic circuit: saturated and non-saturated.
Study of D.C. generators: operation, back e.m.f., commutation, power and torque, methods of excitation, coupling.
Study of D.C. motors. Properties of motors as affected by the method of excitation.
Various D.C. motors: cyclic motors using the flux of the armature reaction, acyclic motors.
Study of balanced poly-phase systems.
Study of unbalanced poly-phase systems by the method of symmetrical components.
Calculation of the short-circuit currents in a symmetrical three-phase network.
General methods for studying networks.
Dipoles and quadripoles: graphical and analytical study, basic diagram and others.
Some applications of matrix calculus to the study of typical circuits.
Coils with iron cores: single- and three-phase.
Study of single-phase transformers with two windings: complete theory by the method of separation of losses, by using the leakage self-inductances, by Kapp's diagram, by the direct quadripole method; equivalent circuits and other diagrams; practical study of the operation of a transformer.
Study of three-phase transformers with two windings; method of connexion, relative phases of the voltages, operation under balanced, unbalanced, and non sinusoidal conditions.
Special transformers: auto-transformers, Scott and Leblanc wiring, transformers with three windings.
Magnetic fields of A.C. machines: rotating fields.
Study of synchronous machines, single- and three-phase; operation, armature reaction, Potier and Blondel diagrams, prior determination of the excitation under load, losses, efficiency, torque, production of harmonics in the voltage, operation under unbalanced conditions, operation under load of a machine connected to a source of infinite power; parallel coupling of two synchronous machines; natural and forced mechanical vibrations.
Rotary converters: ratio of the no-load e.m.f.'s, transformation ratio of the currents, ohmic potential drop and Joule losses in the armature; armature reaction, operation under load.
Study of polyphase asynchronous machines: operation, starting, speed regulation of motors; synchronous induction machines, asynchronous starting of synchronous machines, automatic synchronous excitation on capacitances. Asynchronous single-phase machines. Phase-balancing machines.
Study of polyphase machines equipped with commutators: fixed or rotating ring located in a rotating field; collector ring rotating in its own field; shunt- and series-wound motors, commutator machine in cascade with an asynchronous motor.
Single-phase commutator motors: compensated series motor, repulsion motor.
Study of transient conditions by the algebraic method, by complex quantities, and by symbolic calculus.
Transient conditions in circuits with lumped constants: free oscillation, change of state of any kind, discharge, sudden charging, sudden opening of circuit.
Transient conditions in D.C. machines; excitation of a series generator, excitation on load of a shunt-wound generator, sudden change of voltage across the terminals of a shunt-wound generator.
Transient conditions in transformers: sudden energizing, change of operating conditions.

Transient conditions in A.C. rotating machines: change of conditions, building-up and decay of the rotating field, short-circuiting of polyphase synchronous or asynchronous machines; voltage across the terminals at the instant of cut-off.
Introduction to the study of the stability of servo-mechanisms and regulators; various criteria; regulation of the speed of a turbine and of an alternator.
Study of A.C. transmission lines: definition of the conditions at a point of a single-phase circuit, of a symmetrical poly-phase circuit, line constants.
Study of circuits with constants uniformly distributed under stationary conditions; general equations, relations between conditions at the ends of a circuit; resolution of a stationary state into two moving waves, and into four stationary waves; general properties and behaviour of lines of various lengths.
Study of circuits with uniformly distributed constants, under transient conditions, by the symbolic calculus, and by the method of moving waves.

ELECTRICAL MEASUREMENTS

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

The C.G.S. units: electrostatic and electromagnetic systems, ratio of units.
Giorgi's rationalized and non-rationalized systems.
Study of the movement of a moving coil galvanometer. Critical condition, quasi-periodic condition, optimum damping, damping used in practice.
Sensitivity of a galvanometer, as a voltmeter, as an ammeter, practical sensitivities. Development of technique, need for a small moment of inertia. Limiting sensitivity, Brownian movement.
Ballistic galvanometer: sensitivity under critical conditions, sensitivity in coulombs. Applications of the ballistic galvanometer: measurement of capacitances, induction coefficients, of a variation of flux, of the mechanical and electrical constants of a galvanometer, the logarithmic decrement, and the period.
Moving magnet galvanometer.
Resonance oscillographs and galvanometers. Potential and current resonance. Formal identity of the equations of mechanical systems and of electrical circuits. Optimum conditions. Acuteness of resonance.
Ammeters and voltmeters of various types; temperature correction, universal shunts. Application of these instruments to industrial practice. Measurement of the internal resistance of a cell and of an accumulator. Measurement of resistances: Hocking and Mathiessen's method. Example of the application of Thévenin's theorem. Potentiometer with three terminals.
Grassot fluxmeter, shunted fluxmeter, fluxmeter used in chronometry.
D.C. meters: O'K, Elihu-Thomson, mercury.
Measurement of e.m.f.'s and potentials by the opposition method: Bouty's method. Various potentiometers. Calibration of ammeters and voltmeters; standard cells.
The quadrant electrometer: heterostatic and idiostatic connexion. Industrial use of the 3-electrode electrometer.
Electrodynamic apparatus: electrodynamometer, electrodynamic ammeter and voltmeter, ammeter with several ranges.
Logometers of the first type: application to the measurement of resistances; electrodynamic phase meter, use on three-phase current. Use of the logometer as a frequency meter; phase indicator or synchronoscope. Lincoln frequency meter, recording soft-iron meter with high sensitivity, vibrating reed frequency meter.
Logometers of the second type (Hartmann and Braun), three-phase use.
Electrodynamic wattmeters. Fundamental study of the Fraser winding for the correction of wattmeters; application to the theory of induction ammeters and coil rotors. The Michel and Turner H.F. ammeter; use in three-phase distribution, use of three and of two wattmeters. Measurement of the active and reactive components of power.
Induction meters for single and polyphase circuits. Meters for reactive component, or var-hour meters.
Measuring apparatus making use of the properties of rotating fields. Ferrari's induction wattmeter. Measurement of cos φ of an unbalanced three-phase system, using a moving-iron rotating field phase meter.

Generalities on magnetism. Measurement of magnetic field, in an air gap, using the bismuth coil technique, the Lippmann mercury ammeter, the Cotton balance, the ballistic galvanometer, the fluxmeter, gaussmeter, etc.
Measurement of ferromagnetic quantities. Measurement of permeability by the torus method; plotting of a hysteresis curve by Rowland's and Ewing's methods. Picou's and Iliovici's permeameters. Measurement of the rotating hysteresis by the Blondel hysteresimeter.
Permanent magnets: Evershed's criterion, Watson's hyperbola, Picou's equation. Development of a design for a magnet: choice of materials.
Action of A.C. Measurement of the loss angle for dielectrics, the hysteretic angle of phase advance for magnetic materials.
Principle of measurements of losses in the iron by Epstein's method, and by the Wheatstone bridge method.
Iron core inductances: various definitions. Rayleigh inductance. Jordan coefficient.
Soft-iron ammeters and voltmeters. Properties of nickel steels. Apparent optimum permeability of a coil under the simultaneous action of a constant and an alternating field.
Measuring apparatus using valves with several electrodes: peak voltmeters.
Voltage and current amplifiers. Linear and non-linear distortions, reaction and feed-back, Nyquist's criterion.
The electrometer valve: measurement of currents of the order of 10^{-14} A.
Voltage stabilizers.
Periodic harmonic and relaxation phenomena. The frequency divider; application to the measurement of the frequency of a tuning fork. The multivibrator: application to the construction of an electronic switch.
The cathode ray oscillograph: scanning and magnetic or electrostatic focusing, time base. Application to electrical measurements: of impedance, power, and the plotting of a hysteresis loop.
Telemetering: telemetering by proportional current by pilot wires, and at variable frequency by carrier currents.
The principles of the Wheatstone bridge. Effect of parasitic capacitances, the double screen device, and that of Wagner. Comparison of resistances, of induction coils, capacities, mutual inductances and impedances: description of numerous circuits.
Study of the sensitivity of a Wheatstone bridge on D.C. and on A.C.
The opposition method on A.C.: potentiometers and compensators: various measurements.
Transformers used in measuring technique: current and potential transformers; effect of hysteresis. Use of current and potential transformers coupled to a wattmeter for measuring power. The transformer regarded as a matcher of impedances.
Revision of the theory of symmetrical components of a three-phase system, a two-phase system (currents and potentials). Equivalent three- and two-phase systems. Measurement of the symmetrical components with induction apparatus.

PRACTICAL WORK (students in groups of two)

Measurements of resistance and potential differences on D.C. Measurements of resistance on a Wheatstone bridge; study of the sensitivity of the bridge and the accuracy of the results. Measurement of the resistance of a galvanometer. Measurement of resistances by voltmeter-ammeter methods. Measurement of high resistances. Measurement of low resistances by Thomson's double bridge. Measurement of resistance with a potentiometer. Measurement of potential differences on a potentiometer. Measurement of the insulation resistance of a capacitor. Measurement of the resistance of a ground plate. Measurement of the internal resistance of a battery accumulator.
Measurement of impedances and phase angles on A.C. Measurement of the self-inductance of a coil by Joubert's method. Measurements of loss angles and capacities on the Wien-Nernst bridge. Measurement of the constants of a coil on an inductance bridge. Measurement of self-inductances and phase angles on a Maxwell bridge. Measurement of coil constants on a Hay bridge. Measurement of the constants of an electrolytic condenser. Measurement of the constants of a metal rectifier.
Various measurements on H.F. Measurement of various impedances on the Q-meter, on T and double-T bridges.

Measurement of power and energy. Measurement of power using three voltmeters. Single-phase induction meters: regulation and calibration. Three-phase meters: circuit and use. Watt-hour meters for D.C., calibration and use.

Calibration of measuring apparatus. Calibration of an ammeter and a voltmeter on D.C. Check of ammeters and voltmeters on A.C. Calibration of an electrodynamic wattmeter with a potentiometer.

Measurements of magnetic quantities. Study, and various applications, of a Grassot fluxmeter. Plotting of a hysteresis loop by Ewing's method. Measurement of the permeability of a straight strip sample with an Iliovici permeameter. Measurement of total losses on A.C. by Epstein's method. Study of a ferromagnetic material in weak alternating fields: permeability, hysteresis loss, eddy currents, coupling hysteresis effect.

A.C. circuits. Study of a resonant and rejector circuits: damping. Study of two inductively coupled circuits. Characteristics of a filter or a quadripole at L.F. Harmonic analysis of a complex A.C. potential.

Transformers and compensators (induction regulators). Calibration of a current or potential transformer at 50 c/s. Measurement of the constants of an L.F. transformer. Opposition method for A.C. compensators.

Various materials and apparatus. Measurement of the electrical and mechanical constants of a galvanometer: stationary and ballistic conditions. Measurement of constants of electromagnetic relays: response times. Measurement of the dielectric constant and the loss angle for a material: effect of temperature on electrical properties.

Various experimental demonstrations. Electronic control of a D.C. motor. Inverter: transformation of D.C. into A.C. Wheatstone bridge with automatic control (servo-mechanisms). Frequency divider controlled by a tuning fork. Distribution of current in the cross section of a conductor: skin effect. Study of lines of force in a space; analogous spherical cap. Oscillographic display of the impedance curve of a circuit. Harmonic analysis of a rectangular wave. Distribution of lines of magnetic force in the air-gap of a rotating machine: effect of a phase-shifting ring. Direct projection of oscillograph images on a large screen. Experimental analysis and functioning of the various circuits of a large demonstration amplifier. Check of the resistance of a number of resistances, of the same nominal value, connected in series, and of samples of magnetic materials.

EQUIPMENT (for 360 students, divided into two series, doing the experiments in turn)

Quantity	Item and characteristics	Total cost in dollars
	Substation for Supply of Electricity to the "Electrical Measurements" Section (see p. 28).	
	General Equipment	
1	Main laboratory, 36 × 13 × 4.5 m (supplied with current from batteries), for first-year work, equipped with:	
	2 general distribution boards (1 for "voltage" with an output of up to 5 A, the other, marked "current", with an output of up to 30 A), enabling any particular circuit to be connected to the feeder circuits	12,400
	42 benches (1.5 × 0.9 × 0.9 m) with built-in distribution boards, comprising 3 independent 115 V supply points (1 protected by a fuse for supplying the lamps for galvanometers, the other 2 protected by cutouts, for feeding the measuring apparatus), 1 current supply to 7 plugs, for feeding clocks driven by synchronous motors, 1 galvanometer with several sensitivity ranges, and a scale of 300 mm, either independent or built-in (each board is connected to 2 general distribution boards by a "voltage" and a "current" line protected by cutouts)	10,500
1	Power lines laboratory (supplied with current directly from batteries and indirectly by converter sets through a 2 kVA isolating transformer) intended for the general study of power lines, the distribution and transport of power (second year) equipped with:	
	16 benches, special type (1.8 × 0.9 × 0.9 m) with their own distribution boards, comprising, in addition to the equipment located on the boards of the benches in the main laboratory, one three-phase	
	Carried forward	22,900

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	22,900
	input, 4 wires from the 2 kVA isolating transformer, protected by a contactor-circuit breaker, 2 co-axial inputs (for L.F. and H.F. supplies), 1 dry cell, or accumulator (for D.C. bridge work)	5,200
1	Special room for bridge work (specially silent to facilitate the proper use of telephone detectors, and supplied with current in the same way as the power lines laboratory) for setting up D.C. measuring bridges or those operating on current at audible frequency (first year), equipped with 4 special benches	1,320
1	Room for bridge work similar to the last, for second-year practical work, containing 12 special benches	3,960
1	Rotary generator laboratory (fed directly from the converter sets) for iron tests under sinusoidal conditions, for the study of superposition of sinusoidal voltages and of those having a complex waveform, for the calibration of single-phase meters and wattmeters, for the study of L.F. circuits requiring a certain amount of power, equipped with 4 ordinary benches	400
1	Special tests laboratory, for the study of earthing plates, instrument transformers, symmetrical components, three-phase meters, equipped with:	
	2 distribution boards similar to those in the main laboratory, but smaller in size, adapted for the output of currents less than 4 or than 30 A, at variable voltages	1,600
	6 special benches	1,980
1	Demonstration laboratory, for the various demonstrations included in the syllabus, containing 4 special benches	1,320
1	High tension laboratory, for carrying out tests at voltages up to 200 kV, 50 c/s, and high frequency tests at up to 200 kc/s (tests on the dielectric strength of various insulators, tests on the flash-over of post type insulators, and on chains of insulators, examination of the behaviour of an insulator under high-frequency discharges, etc.), equipped with:	
	2 single-phase oil-cooled transformers, 200 V/30-100 kV, 20 kVA, with a connecting switch for obtaining 200 kV; 1 oil-filled single-phase transformer, 200 V/1-3-9 kV, 1 kVA; 1 instrument transformer, step-down, ratio 70,000/100 V; 1 Tesla transformer with condensers and spark gaps; 1 sphinterometer; 1 Abraham-Villard electrostatic voltmeter, 1 microfuse for 10 kV, 25 mA, and 1 for 7 kV, 50 mA; some H.T. neon discharge tubes; some insulator chains; 1 bench for determining the breakdown strength of solid insulators, 1 apparatus for testing oil, in total	3,800
	Total	42,480

Measuring Equipment and Apparatus

30	D.C. control boxes, each containing 1 ammeter and 1 voltmeter, moving coil types, and an assortment of shunts	3,300
20	A.C. control boxes, each containing 1 ammeter and 1 voltmeter, moving iron, with several ranges	2,400
6	Universal controllers, small type	330
12	Universal controllers, large type	840
4	Electronic controllers	720
20	Single-phase meters	360
8	Three-phase meters, for active component	280
8	Three-phase meters, for reactive component	280
12	Ampere-hour meters, for D.C.	240
12	Watt-hour meters, for D.C.	270
16	Various meters	320
16	Electric clocks driven by synchronous motors, for tests of power meters	1,080
	Carried forward	10,420

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	10,420
24	Mechanical chronoscopes	480
4	Precision revolution counters (tachimeters), 0-20,000 r.p.m.	240
2	Stroboscopes, 0-16,000 r.p.m.	200
40	Moving coil ammeters, with several ranges	2,800
84	Ammeters, moving iron, with several ranges	3,960
30	Ammeters, rectifying, with several ranges	1,500
20	Ammeters, dynamometer	1,840
12	Ammeters, thermo-couple	840
24	Milliammeters, with several ranges	1,200
8	Milliammeters, rectifying, with several ranges	440
12	Milliammeters, moving coil	660
6	Galvanometers, differential	288
8	Galvanometers, thermocouple	300
8	Galvanometers, for measurement of insulation	720
6	Galvanometers, calibrated, with lamp and scale	720
12	Galvanometers, large scale, with range switch	1,440
6	Ballistic galvanometers, several periods, illuminated scale	780
8	Galvanometers, vibration, for frequencies of 10-600 c/s	640
2	Galvanometers, Broca, moving magnet[1]	120
40	Voltmeters, moving coil, with several ranges	2,800
60	Voltmeters, moving iron, with several ranges	3,000
24	Voltmeters, rectifying, with several ranges	1,200
20	Voltmeters, panel mounting, various ranges	300
8	Voltmeters, thermocouple	560
2	Voltmeters, induction	100
4	Voltmeters, ordinary electrostatic	440
2	Voltmeters, electrostatic, multicellular	480
16	Millivoltmeters, with several ranges	720
8	Millivoltmeters, with several ranges and illuminated scales	640
16	Voltmeters, electronic, A.C. and D.C.	3,600
2	Voltmeters, peak	320
2	Voltmeters, with electrometer valve	540
8	Millivoltmeters, amplifying, L.F.	1,980
2	Millivoltmeters, amplifying, special	540
4	Potential transformers, for H.T. voltmeters	160
4	Electrodynamometers, suspension, interchangeable	960
4	Quadrant electrometers, illuminated scale	540
32	Wattmeters, dynamometer, various ranges	320
4	Wattmeters, special, for measuring iron losses	840
2	Wattmeters, electronic	400
1	Wattmeter, output, for amplifiers	108
	Additional resistance and current transformers, for wattmeters	120
6	Ohmmeters, magneto	390
2	Ohmmeters, battery operated	70
2	Ohmmeters, tellurium	168
2	Megohmmeters, electronic	240
2	Megohmmeters, bridge, 10^6 MΩ	420
36	Resistance boxes, 6-decade, precision	4,620
180	Resistance boxes, 4-decade, precision	14,400
320	Resistance boxes, decade, divisible	3,520
12	Resistance boxes, containing 4 double decades	2,820
12	Resistance boxes, double arm, for double bridge	640
18	Resistance boxes, ratio	960
8	Resistances boxes, high current-carrying capacity, for special tests	640
16	Resistance boxes, 1 MΩ, subdivided	640
	Carried forward	79,784

[1] This list of galvanometers does not include those built into the benches, and whose cost is included in the cost of these latter.

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	79,784
16	Resistance boxes, decade, 100,000 Ω	1,080
6	Admittance boxes	600
24	Resistances for protecting standard cells	160
6	Standard resistances, 1,000 Ω to 0.01 %	224
4	Standard resistances, 100 Ω to 0.01 %	148
4	Standard resistances, 10 Ω to 0.01 %	148
4	Standard resistances, 1 Ω to 0.01 %	148
4	Standard resistances, 0.1 Ω to 0.01 %	152
4	Standard resistances, 1 MΩ to 0.1 %	96
12	Standard resistances, 1 Ω to 0.1 %	154
18	Standard resistances, 0.1 Ω to 0.1 %	224
12	Standard resistances, 0.01 Ω to 0.1 %	154
6	Standard resistances, 0.001 Ω to 0.1 %	78
24	Boxes of capacitances, paper dielectric, subdivided	1,640
18	Boxes of capacitances, mica dielectric, subdivided, with plugs	1,240
24	Boxes of capacitances, decade, air dielectric, vernier	5,400
8	Boxes of capacitances, 100 µF, paper dielectrics, for special tests	1,440
18	Capacitors, dielectric, calibrated, normal type	480
12	Capacitors, dielectric, precision, variable	2,700
48	Capacities, fixed, paper, mica, or polystyrene dielectrics	96
86	Rheostats, 200-400 W, various resistances between 0.3 and 1,200 Ω	1,720
64	Rheostats, 100 W, variable section for constant voltage use	1,540
64	Potentiometers, 1,000 Ω, 6 W, in moulded containers	480
75	Potentiometers, 200-400 W, various resistances between 20 and 8,000 Ω	11,650
75	Potentiometers, 6 W, various resistances between 200 and 150,000 Ω	300
12	Potentiometers, slide wire, 1 Ω, divided scale	480
4	Potentiometers, slide wire, 1 Ω accurate to 0.1 %	720
5	Potentiometers, industrial, Iliovici type, with accessories	3,250
4	Potentiometers, industrial, precision, with accessories	1,440
2	Potentiometers, industrial, for thermocouples	500
4	Potentiometers, industrial, portable	720
8	Potential dividers, for potentiometers	320
6	Wheatstone bridges, D.C., portable, precision	660
8	Bridges, slide wire, portable	420
2	Bridges, for fault detection (P.O. boxes)	300
50	Bridges, in boxes, with plugs	3,860
8	Bridges, boxed, with multipoint switches	640
8	Bridges, A.C., 50 c/s, for measuring resistances and capacitances	960
3	Bridges, impedance, laboratory	1,200
2	Q-meters, service	800
2	Q-meters, precision	2,660
3	Sets of calibrated coils, for Q-meter	300
36	Telephone headsets, ordinary	216
18	Telephone headsets, adjustable	200
4	Coils, Ayrton-Perry	1,040
6	Coils, with movable iron cores	300
12	Fluxmeters, pivot	2,050
4	Fluxmeters, suspension and mirror	824
4	Fluxmeters, with automatic return to zero	1,100
4	Gaussmeters, crystal	120
2	Gaussmeters, crystal, special	104
2	Gaussmeters, electronic	684
6	Permeameters, Iliovici	1,880
1	Permeameter, electronic	314
12	Phasemeters, single-phase	1,270
2	Phasemeters, single-phase, precision	412
2	Phasemeters, three-phase	216
1	Phasemeter, electronic	400
	Carried forward	142,196

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	142,196
4	Phase-shifters, three-phase	790
8	Rheostats, transformer, for phase shifters	1,460
8	Prepayment boxes, for meters.	272
1	Henrymeter, direct reading, for 50 c/s	105
1	Hysteresimeter, Blondel	345
1	Hysteresimeter, Elliott	160
8	Filters, low-pass, for A.C. bridge work, 50 c/s	88
4	Filters, band-pass, for measuring bridge, audible frequencies	112
2	Filters, band-pass, for variable frequency	684
6	Filters, band-stop, double T	62
6	Frequency meters, vibrating reed; precision	590
4	Frequency meters, needle, standard	940
4	Frequency meters, electronic, direct reading	940
	Frequency meters, various, normal type	180
24	Oscillators, L.F., normal type	4,250
6	Oscillators, L.F., stabilized	1,730
2	Oscillators, L.F., high stability	820
8	Oscillators, L.F., RC	1,420
6	Oscillators, L.F., fixed frequency	788
2	Oscillators, L.F., saw-tooth output	194
4	Oscillators, L.F., rectangular wave output	1,600
2	Oscillators, L.F., for very low frequencies (0.1-1,000 c/s)	1,185
1	Generator, pulse	2,800
2	Oscillators, H.F., normal type	540
2	Oscillators, H.F., laboratory type	1,040
1	Frequency modulator, with oscillograph	250
4	Amplifiers, L.F., for loudspeaker	412
4	Amplifiers, 25 W	640
12	Preamplifiers, for cathode ray oscillograph	2,950
1	Amplifier for high speed recorder	640
16	Amplifiers, measuring, 85 db	3,740
12	Amplifiers, measuring, small size, cathode cross	820
12	Amplifiers, miniature, battery operated, for bridges	960
2	Amplifiers, selective, for special tests	1,440
16	Attenuator boxes, 111 db	2,740
4	Alternators, H.F.	948
2	Distorsiometers, L.F.	804
1	Harmonic analyser, for 50 c/s	1,000
1	Harmonic analyser, for L.F.	2,140
1	Analyser, Coradi	2,060
1	Wavemeter, Hospitalier	372
12	Cathode ray oscillographs, normal type	1,860
4	Cathode ray oscillographs, laboratory type, L.F.	1,370
2	Cathode ray oscillographs, laboratory type, H.F.	744
3	Cathode ray oscillographs, double channel	640
1	Oscillograph, electromagnetic, Blondel (Duddel)	1,370
6	Oscillographic equipments, various	498
1	Oscillographic recorder, multiple channel	1,940
	Various accessories, recording camera, camera lucida, etc.	400
60	Rectifiers, dry, various types	180
12	Rectifiers, thermionic, for measurement of high resistances	224
6	Power packs, voltage-stabilized, for measurement of high resistance	890
4	Power packs, voltage-stabilized, for tests of valves	972
1	Synchronoscope, for single-phase synchronization	191
12	Transformers, current, H.T.	436
12	Transformers, current, portable	274
6	Transformers, potential	216
12	Transformers, screened, normal type	184
6	Transformers, screened, variable ratio	180
	Carried forward	199,776

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	199,776
6	Transformers, double screened	174
32	Transformers, screened, 1 W, 20-20,000 c/s	960
8	Transformers, coupling, L.F.	124
8	Transformers, power, L.F.	148
24	Transformers, various, small types, 50 c/s	82
10	Transformers, various, 100 W, 50 c/s	80
20	Auto-transformers, single-phase, 300 VA to 2 kVA	640
2	Auto-transformers, three-phase, 6 kVA	420
2	Ovens, hot air	186
1	Furnace for thermal treatment, with accessories	234
1	Apparatus for pH measurement, with special potentiometer	376
1	Collection of apparatus for the study of piezo-electricity	525
1	Collection of apparatus for studying mechanical vibrations	274
1	Complete set for telemetering	2,150
1	*Communication receiver*	272
2	Power packs, high stability	440
2	Electronic switches, 2 way	343
2	Electronic switches, 3 way	544
1	High-speed recorder, for L.F. with its own amplifier	544
1	Turntable	52
1	Valve meter with a collection of valves	308
5	Ewing apparatus, for plotting hysteresis loops	270
3	Epstein-Armagnat apparatus for measuring total losses in iron	788
1	Coil, dismountable, for the study of anchor-ring ferromagnetic samples	252
1	Coil, dismountable, for various experiments	24
8	Motors, universal	176
2	Motors, stabilized, for mechanical oscillography	120
6	Micromotors, for remote control	163
10	Standard cells, H-form	154
18	Standard cells, concentric, miniature	216
40	Accumulators, various, lead and Cd-Ni	240
40	Single pole reversing switches	72
40	Double pole reversing switches	96
16	Relays, mercury reversing, vacuum	216
48	4-point switches, on insulating pillars	1,230
24	Sabine switches, for capacitances	1,270
12	Switches, 3-point, for capacitances	72
16	Switches, double, for capacitances	234
24	Switches, two-contact	124
16	Switches, reversing, for galvanometers	48
00	Equipments for examination	1,250
	The following apparatus is supplied to the demonstrators for carrying out certain experiments in front of groups of students.	
1	Apparatus for demonstrating skin effect at 50 c/s, in massive conductors, with currents of the order of 1,200 A	246
1	Electrolytic tank for studying the distribution of electrical field in a homogeneous medium under steady conditions	234
1	Tuning fork, 1,000 c/s, excited by valves, equipped with a frequency divider, 3-stage, down to 1 c/s	357
1	Amplifier, comprising the following circuits: input stabilization, voltage, power, reaction and feedback, L.F. transformer with several tappings, and all circuits accessible for oscillographic display	352
1	Strain gauge equipment on a machine-tool	252
1	Inverter, thyratron, with oscillographic study of all parts of the circuit	190
1	Cathode ray tube with large screen (27 cm) with arrangement for viewing screen from both sides	540
	Carried forward	217,838

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	217,838
1	Galvanometer, with large scale, and luminous spot, scale illuminated by light diffused from the white-painted interior walls of the housing	194
1	Electromagnet	146
1	Wheatstone bridge, self-balancing, as illustration of the operation of electronic servo-mechanisms	252
1	Rotary converter (generator) D.C., thyratron-controlled, with arrangement for oscillographic display of all stages of the control mechanism	275
1	Special set-up, permitting the oscillographic display of the following experiments: valve characteristic, rectifier characteristic, characteristic of a phase-shifting ring—with square and saw-tooth pulses, charge and discharge of a condenser, development of a current in any circuit, selection of harmonics from a complex voltage, rate and acceleration of mechanical deformation of solids	340
	Total	219,045

ELECTRICAL MACHINES

Course Content (given only as an example to facilitate the use of the inventories)

Introduction to the Study of Electromagnetic Machines

The families of electromagnetic machines. Features common to all: constituent materials, magnetic and electrical circuits; fundamental laws of electromagnetism expressed in a form suitable for the study of machines. Elements of technology.

Machines with cylindrical cores: general constitution, application of the fundamental laws.

Machines having rotational symmetry: general constitution, application of the fundamental laws, expression of the operation of normal machines in terms of equations.

The machine from the constructor's point of view: losses and efficiency, heating, and ventilation, insulation, commutation, electrical calculations.

The machine from the user's point of view: normal magnitudes, Joule heating, life-time, characteristics, control, protection, instructions for use and maintenance.

General references to abnormal conditions: harmonics, unbalanced and transient conditions.

The why and the how of operation, under normal and abnormal conditions: of static transformers, of synchronous machines, of asynchronous motors, of D.C. machines, and of various special machines.

Technology associated with the electric motor. The problems to be solved by the installation engineer.

The course is accompanied by many numerical exercises (with discussion sessions) restricted to problems which are actually encountered in industry, or corresponding to existing projects.

Winding of Electrical Machines

The insulation of windings. General study of the various insulators: liquids (mineral oils, halogenated hydrocarbons, silicones), solids (organic, inorganic, mixed). Drying and impregnation of windings. Heating limits for windings.

Closed windings: spirals, sections, and coil. Various types of windings: conditions of use, selection of method of winding.

Field windings, auxiliary and short-circuit windings.

Phase winding of A.C. stators and rotors.

Shortened pitch, parallel circuits and modification of the number of phases.

Supplementary losses in the leads.

Checking of windings.,
Standardization of windings.

Design and Construction of Static Electrical Machines

Magnetic circuits:
Construction: magnetic laminations, shell and core types, joints, forms of sections, assembly. Calculation of iron losses, of magnetization current, and of the current at switching on.

Windings:
Construction: concentric and wave windings, L.T. and H.T. windings; construction, treatment, and connecting up. Calculation of the overall dimensions of windings, losses, potential drops, and electrodynamic forces. Normal coupling and grouped couplings: schemes and diagrams. Parallel connexion. Various factors affecting this form of connexion for two transformers: polarity, transformation ratio, impedance potential, angular phase displacement between the voltages in the primary and secondary, vectorial rotation, magnetizing current, ratio of the resistance to leakage reactance.

Insulation:
Study of insulators used in the construction of transformers. Determination of the stresses between the elements of the apparatus. Practical insulation schemes.

Heating and cooling:
Measurement and calculation of heating effects. Natural and artificial methods of cooling.
The design of a transformer: practical example.

Design and Construction of Rotary Electrical Machines (Electrical Part)

General methods of calculation.
Revision of certain fundamental ideas: the e.m.f. induced in the armature of a machine on A.C., on D.C., with non-identical coils. Study of magnetic materials. Different qualities of sheet for laminations: their magnetic and physical properties. General rules for dimensioning. Characteristic magnitudes and fundamental relationships. Characteristic fundamental parameters, and laws of proportionality. General study of the magnetic fields associated with rotating machines. Different magnetic fluxes in a machine. Different methods of study of magnetic fields: analytical and graphical procedures. Lehmann's method; experimental methods. Study of the permeance of the air-gap in a machine. Calculations for armatures. Rough outline of calculation. Details of calculation: selection of number and size of the armature slots. Calculation of losses. Calculation of ampere-turns. Calculations for the field magnet. Exciting current. Calculation of losses. Normal losses in iron, in copper, by friction at the brushes, at the bearings, by ventilation, etc. Additional losses on no-load and under load. Calculation of Joule heating. Analytical calculation of the heating in stators. Practical methods for the calculation of heating effects. Heating of machines in temporary or intermittent service. Various magnetization curves, and loss curves. Some normal values.

Practical methods peculiar to each category of machines:
Calculations for D.C. machines. Generators and motors. Rotary converters. Numerical examples. Normal calculations for alternators and synchronous motors. Alternators with salient poles. Turbo-alternators. Synchronous motors and condensers. Special calculations on synchronous machines. Constants for variable conditions. Homopolar alternators. Calculations for induction machines. Rotating coil motors. Short-circuit (squirrel-cage) motors: simple cage, double cage, with deep slots. Numerical examples. Elements of calculations for A.C. machines with commutators: practical methods such as those used in design offices.

Design and Construction of Rotary Electrical Machines (Mechanical Part)

Calculations of the strength of materials used for the main parts of such machines:
Calculations for rings and discs: constant and variable axial thicknesses, low radial

thickness. Application of formulæ for rings: forcible connexion, calculation of flywheels for radial forces. Calculation of shafts for rigidity and strength; flexures and elastic deformations, critical flexure and torsional speeds. Assembly by screwing, by dovetailing, and by keying.

Description of, and calculations for, the elements of rotary electrical machines:
Stationary field systems for constant and variable flux. Rotating field systems for constant and variable flux. Current collecting devices: split-ring commutators; slip rings; brushes and brush-holders. Centrifugal and helical fans. Bearings. General lubrication theory, practical results. Plain bearings: housings and bushes. Fixed bearings, ball- and roller-bearings.

L.T. Equipment for Electrical Machines

Operation and control equipment:
Fundamental data about such equipment: passage of normal current, thermal effects, normal current interruption. Operation and control of generators. Basic schemes. Isolators and switches, starting rheostats, control rheostats. Operation and control of motors. Basic schemes. Resistances and rheostats with examples of calculations, multipoint switches, electrical and mechanical contactors, relays, and mechanical and electrical control equipment. Grouping of equipment. Various layouts: unifilar, developed, wiring diagrams. A.C. and D.C. motors: circuits for starting, stopping, and speed regulation.

Protective equipment:
Fundamental information about devices for protection against surges and short-circuits: thermal and electro-dynamic effects, contact making and breaking. Protective relays, fuses, cutouts. Grouping of apparatus in boxes and on boards: various methods of mounting and protecting against impulses and external disturbances.

Tests on Electrical Machines and Practical Study of their Properties

D.C. machines:
Generators: separate, shunt, series and compound excitation. Recording the characteristics on no-load and on load. Armature reaction. Measurement of the resistance of the various windings. Action of the compoles. Special dynamos: three-brush dynamos, machines of constant current intake or torque, Rosenberg dynamo, rototrol, amplidyne. Motors with shunt, series, and compound windings. Speed and torque characteristics. Speed control. Torque measurement; use of various kinds of brakes and dynamometers, of electrical or magnetic strain-gauges; method based upon the measurement of acceleration. Coupling of dynamos and motors in parallel. Stability problems, and methods adopted for improving the stability. Measurement of heating effects. Studies on ventilation of machines. Determination of the efficiency: directly, by opposition, by separating the losses, or from calculation; additional losses. Comparison between various methods. Experimental study of commutation. Faults and remedies. Information about the various kinds of brushes.

Alternators and synchronous motors:
No-load and on-load characteristics. Indirect methods (Bohn-Eschenburg, Potier, Blondel). Sudden short circuits: forces and torques brought into play. Measurement of the various resistances and time constants. Heating tests. Construction of starter resistances. Measurements of efficiencies. Inertia constants. Coupling of alternators. Coupling of several synchronous motors in parallel: application to the case of three machines. Means for starting synchronous motors and measurement of torque. Automatic excitation on capacitance. Experimental study of excess voltages due to resonance and ferro-resonance.

Single- and poly-phase asynchronous motors:
Blondel and practical diagrams. Torque, slip, power factor, leakage coefficient. Efficiency. Separation of hysteresis losses. Jorgi and creeping phenomena. Braking. Asynchronous generators. Selsyns. Asynchronous motors associated with frequency changers: vector diagram and analytical theory. Commutator motors: auto-compensated and Schrage. Repulsion motors: Latour motor.

Transformers:
Generalities. Kapp diagrams. Measurement of efficiencies: by separating the losses, and by opposition. Heating effects. Coupling in parallel. Insulation tests. Treatment of the oil. Tests on shock waves. Design of a shock wave generator. Determination of the voltage ratio under the effect of shock waves.

Rotary converters:
Voltage ratio, current ratio. Control of the D.C. voltage, armature reaction, commutation. Starting. Parallel running.

Miscellaneous:
Eddy currents in shafts and bearings: origin and measurement, remedies. Vibration and noise of machines: origin and measurement, remedies. Flexible mountings. Sound-proofing of machines. Balancing of rotating machines. Theory of balancing (static and dynamic). Balancing on the test bench, and after installation. Balancing machines. Electronic circuit for controlling the voltage and the speed of machines. Automatic cyclic variation. Choice of measuring instruments. Accuracy of various kinds of instrument commonly used. Calculation of errors.

Rectifiers

Generalities on current rectifiers: internal potential drop, the inverse voltage, calculation of the rectified voltage; various methods of filtering the rectified current. Study of the transformer-rectifier combination. Electrolytic rectifiers. Dry rectifiers. Valve rectifiers using an incandescent filament cathode. Mercury vapour rectifiers.

Servo-mechanisms

Function of servo-mechanisms. Field of application. Various controllers used in industry and in physics. Examples of servo-mechanisms: governors, automatic pilots.
General constitution of a servo-mechanism. The various input and output quantities.
Detectors and measuring instruments: speed measurement, measurement of displacements, forces, temperatures. Narrow band amplifiers.
Servo-motors and their control systems. D.C. motors fed by rotary amplifiers, relays, etc. A.C. motors fed by magnetic amplifiers, etc. Hydraulic and pneumatic motors. Adjustable and oleomagnetic drives.
Theory of servo-mechanisms. Present position of the problem. The data: accuracy, external disturbances. Elementary theory. Symbolic theory of linear servo-mechanisms: extension to electromechanical systems of the theory of amplifiers with negative feed-back. Frequency bands used.
Stability. Nyquist criterion. Bayard and Bode relation.
The accuracy of servo-mechanisms. Errors. Specifications. Input functions, theoretical and practical. The accuracy in response to sudden signals, and to slow signals.
Non-linear elements in servo-mechanisms. Respective functions of the electrical components and of the associated machine. Concrete examples.

PRACTICAL WORK

Miachne Tests (students in groups of four)

D.C.:
Recording the characteristics of generators and motors with separate, shunt, series, and compound field windings. Determination of the characteristics of special machines: three-brush dynamo, dynauton. Measurement of efficiency by separating the losses, and by direct methods (Cardew-Fontaine, Rayleigh, Potier, Hutchinson, Hopkinson, Blondel). Separation of losses by the retardation method. Armature reactions in motors and generators. Temperature and long-period tests. Stability of parallel connected shunt- and compound-wound generators. Speed stability of shunt- and compound-wound motors.

A.C.:
Single- and three-phase transformers: direct tests on no-load, short circuit, and on load; Kapp's diagram; study of the efficiency. Single-, two- and three-phase

alternators: determination of the characteristics at constant current, constant voltage, and constant excitation for different values of cos φ; method of using the diagram for solving problems involving the dissipative energy. Predetermination of the characteristic of alternators on load by Potier's and by Bohn-Eschenberg's methods, comparison of the results. Measurement of the efficiency of alternators by the method of separation of losses. Aircraft alternators, 250 c/s. Measurement of the reactance under transient conditions. Automatic excitation on capacitance. Measurement of the angle θ (between the internal e.m.f. and the potential across the terminals). Synchronous motors: normal tests, V-curves, active and reactive volt-amperes. Three-phase generators: direct and indirect tests, study of the efficiency as a function of the power factor. Three-phase asynchronous motors: tests on load, on no-load, on short circuit; operation as generators; Blondel's circle diagram; measurement of efficiency by Fourmarier's method. Single-phase asynchronous motors. Pilot motors: three-phase motors connected to a single-phase supply. Auto-compensated asynchronous motors. Asynchronous motors of variable speed obtained via a frequency changer. Latour motors. Repulsion- and repulsion induction motors. Circuits breakers: oscillographic study of the arc formed on breaking contact.

Winding (students in groups of four)

D.C.:

Preparation of former wound coils. Location of coils in the armature slots, and connexion to the commutator. Connexions of the excitation coils for series and shunt windings, and of the commutation windings.

A.C.:

Winding a coil on a coil-winding mandrel and location in a stator. Winding sections on a coil-winding mandrel and location in a stator. Coupling up the coils of one winding of a three-phase rotor and connexion to the slip rings.

Rectifiers

Metal rectifiers: tests and oscillographic studies on various arrangements. Mercury vapour rectifiers, three-phase.

Servo-mechanisms (students in groups of four)

Selsyn transmissions: angle transmitter, "electric shaft". Regulation of a Ward-Leonard set: by amplidyne, by rototrol.

EQUIPMENT (for 360 students, divided into two groups)

Quantity	Item and characteristics	Total cost in dollars
	TESTS ON MACHINES	
	Substation for Electric Supply for this Section (see p. 29)	
	General Installation	
1	Main laboratory, 80 × 13 × 8 m, for tests on rotary machines, equipped with:	
	1 remote control panel, equipped with the same measuring instruments and control devices as on the main sub-station switchboard, with equipment for interruption of all the circuits, in case of accident	7,500
	36 platforms (2.5 × 1 × 1.6 m) bedded in reinforced concrete, covered with wooden planks, 8 cm thick, on which the machines are mounted on rubber anti-vibration mountings, and equipped with switchboards carrying the excitation and starting rheostats, and the shunt mountings; 36 test sets (2 machines per set, on the same foundation, with possibility of replacing one by the other); 36 feeder boards (1 per platform, equipped with contactors and relays for current limi-	
	Carried forward	7,500

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	7,500
	tation, push-button operated, with signal lamps and fuses), supplying the following D.C. outputs: 120 V, 10 A; 120 V, 80 A, 0-210 V, 80 A; and the following A.C. outputs: 115 V, 80 A at 20 platforms for single phase, 115 V, 40 A for two-phase at 8 platforms, and 115 V, 40 A for three-phase at the remaining 8 platforms	21,800
	18 sets of positive and negative boosters (each shared between two neighbouring platforms) each comprising 1 asynchronous squirrel-cage motor, three-phase, 2 kVA, 200 V, 1 generator with separate excitation, variable voltage, 0-±30 V, 80 A, 1 excitation rheostat, 1 switch (steps of 0, 60, 120 and 180 V), 1 reversing switch, 1 signal lamp	11,700
1	Special laboratory for efficiency tests; equipped with two platforms, each carrying two dynamos coupled to brakes, 120 V, 250 A, 2 platforms each carrying 2 shunt-wound generators, 120 V, 250 A, with a driving motor, 120 V, 70 A, coupled to the same shaft, 4 feeder distribution boards identical with those in the main laboratory	2,400
	2 sets of positive-negative boosters (1 shared between two platforms) capable of an output of up to 250 A	2,000
1	Special laboratory for transformer tests, equipped with 10 platforms, 10 feeder boards (1 per platform) supplying: for 8 of the platforms, 115 V, 80 A, single-phase, 115 V, 40 A, three-phase; for 2 platforms, 115 V, 80 A, single-phase, 115 V, 40 A, two-phase	6,000
	1 transformer assembly (step-down, 200/8 V, 40 A) with metal-rectifier and smoothing circuit, permitting D.C. outputs of 6 V, 40 A, for resistance measurements	300
1	Special laboratory (fed by the single-phase alternator of the electricity generating set) for tests at high currents and voltages, equipped with 2 platforms for tests at 100 V, 1,000 A with 2 circuit breakers in cascade for each; one for test, the other for protection; 2 platforms for high-voltage tests, 10,000 V, 10 A, with their circuit breakers; 2 step-up transformers, 100/10,000 V (required for the two last platforms)	750
	4 control panels (for remote operation of the cutouts)	3,000
	Total	55,450

Machines

Rotary machines

Quantity	Item and characteristics	Total cost in dollars
32	Sets of 2 D.C. machines (coupled, on a common base), 6 kW, 120 V, 18 of which sets have separate excitation, 7 have compound, 7 sets in which one machine has series, and 1 machine has separate excitation	32,000
2	Sets of 2 dynamos coupled to brakes, 120 V, 250 A, with separate excitation	6,000
2	Sets of 2 machines, D.C., 120 V, 250 A, with separate excitation, coupled to a third, 120 V, 50 A	7,500
2	Sets, each comprising one three-brush dynamo, 12 V, 20 A, and 1 D.C. motor, 120 V, 10 A, with separate excitation	400
2	Sets each comprising 1 dynauton, 12 V, 50 A, and a D.C. motor, 120 V, 10 A, with separate excitation	550
4	Alternators, single-phase, 115 V, 5 kVA	960
6	Alternators, two-phase, 115 V, 6 kVA	1,500
6	Alternators, three-phase, 115 V, 6 kVA	1,500
2	Alternators, three-phase, 250 c/s, 5,000 r.p.m., 40 kVA	8,200
4	Motors, induction, single-phase, 115 V, 5 H.P.	960
2	Motors, induction, two-phase, 115 V, 7 H.P.	500
8	Motors, induction, three-phase, 115 V, 7 H.P.	2,000
2	Motors, Latour, 115 V, 5.5 H.P.	1,200
2	Motors, self-compensated, three-phase, 115 V, 8 H.P.	1,400
	Carried forward	64,670

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	64,670
1	Motor, repulsion, 115 V, 1 H.P.	100
1	Motor, induction-repulsion, 115 V, 1 H.P.	120
2	Motors, induction, variable speed, 115 V, 6 H.P. each equipped with a frequency changer	7,000
4	Rotary convertors, three-phase, 115/180 V, 35 A	2,400
	Total	74,290

Static machines

Quantity	Item and characteristics	Total cost in dollars
8	Transformers, single-phase, 120/120 V, 6 kVA	1,200
4	Transformers, single-phase, 120/120 V, 30 kVA	1,800
2	Transformers, single-phase, 120/50 V, 12 kVA	500
4	Transformers, three-phase, 120/120 V, 6 kVA	900
2	Transformers, three-phase, 120/24 V, 6 kVA	450
1	Transformer, three-phase, 120/220 V, 6 kVA	225
1	Transformer, three-phase, 120/55 V, 3 kVA	150
2	Transformers, Leblanc, 120/120 V, 6 kVA	600
2	Transformers, Scott, 120/120 V, 10 kVA	720
2	Brakes, Schneider-Fieux, 20 H.P.	4,800
	Total	11,345

Ancillaries

Quantity	Item and characteristics	Total cost in dollars
40	Resistances, starting, with several stud contacts, 12 Ω, 10 A	720
10	Resistances, starting, for three-phase rotors	180
4	Resistances, starting, for three-phase rotors, oil-immersed	72
4	Resistances, starting, for single-phase induction motors	72
70	Resistances, excitation, multiple contact, 120 Ω, 1-5 A	1,750
6	Resistances, excitation, multiple contact, 75 Ω, 1.5-10 A	150
50	Resistances, excitation, with multi-point switch, 400 Ω, 0.3-5 A	1,500
40	Resistances, loading, 1-60 A, 120 V	10,000
2	Resistances, loading, 1-50 A, 12 V	300
2	Resistances, loading, 1-25 A, 12 V	250
4	Self-inductances, single-phase, 0.5-80 A, 120 V	1,200
12	Self-inductances, single-phase, 0.5-40 A, 120 V	3,000
10	Self-inductances, three-phase, 0.5-30 A, 120 V	6,000
2	Capacitors, multiple, 900 μF, operating at up to 200 V, each comprising 6-1,000 μF condensers + 6-50μF condensers	1,200
8	Auto-transformers, 3-phase, variable ratio by sliding contact, primary 115 V, secondary 0-115 V, 30 A	4,000
4	Auto-transformers, three-phase, variable ratio by sliding contact, primary 115 V, secondary 0-115 V, 45 A	1,200
8	Single-pole circuit breakers, 250 A, 200 V	72
8	Single-pole circuit breakers, 80 A, 200 V	24
30	Two-pole circuit breakers, 80 A, 200 V	135
16	Three-pole circuit breakers, 60 A, 200 V	80
16	Four-pole circuit breakers, 60 A, 200 V	96
60	Two-pole switches, reversing, 30 A, 200 V	270
15	Switches, reversing, two-pole, 60 A, 200 V	90
25	Switches, short-circuiting and reversing, for wattmeters, 80 A	250
4	Switches short-circuiting and reversing, for wattmeters, 250 A	72
180	Shunt mountings	3,600
500	Cables, connecting, with lugs, 2 m, 5 mm² cross-section	250
500	Cables, connecting, with lugs, 2 m, 25 mm² cross-section	1,000
100	Cables, connecting, with lugs, 2 m, 100 m² cross-section	800
8	Lamps, mercury vapour, 115 V, 75 W (for measurements of slip)	144
15	Battens holding 2 or 3 lamps, 160 V, 25 W (as resistances)	15
	Total	38,492

Quantity	Item and characteristics	Total cost in dollars
Measuring Apparatus		
75	Control boxes, D.C., each containing 1 *moving-coil* voltmeter, ranges of 3, 15, 75, 150, 300 V and 1 moving-coil ammeter, with shunts for 1, 2, 5, 10, 20, 50, 100, and 300 A	6,000
50	Control boxes, A.C., each containing 1 moving-iron voltmeter, with ranges of 7.5, 30, 150, 300 V, and 1 ammeter, *electrodynamic*, range 5 A, 1 wattmeter, electrodynamic, ranges 30, 150, and 300 V, 5-10 A, 1 current transformer, primary 10, 20, 50, 100, 200 and 600 A, secondary 5 A	14,000
10	Voltmeters, electromagnetic, 5-15 V	300
8	Voltmeters, rectifying, ranges of 3, 7.5, 30, 75, 150 V	480
8	Ammeters, rectifying, ranges of 1, 2, 5, 10, 20, 100 and 200 A	720
10	Cathode-ray oscillographs, L.F.	2,000
2	Oscillographs, recording, 6-tube	12,500
4	Pendulums, releasing	4,000
10	Tachometers, centrifugal type, 400-3,500 r.p.m.	360
30	Tachometers, chronometric type, 300-3,200 r.p.m.	720
6	Tachometers, chronometric type, 600-6,400 r.p.m.	150
1	Tachometer, recording, 100-4,500 r.p.m.	90
12	Chronometers, watch	420
	Total	41,740

Coil Winding

General Installation

Quantity	Item and characteristics	Total cost in dollars
1	Instructional workshop, 100 × 14 m, natural lighting	
Equipment		
20	Armatures, dynamo, 4-pole	900
10	Dynamo carcases, compound	450
10	Rotors for eight-pole asynchronous motors (for three-phase windings)	450
20	Stators for eight-pole asynchronous motors (for single- and three-phase, star and delta windings)	900
1	Assortment of miscellaneous material: copper bars and bushes, armature cores with open and closed slots, reglets, fitting mandrels, mandrels extensible in stages, coils of wire, presspahn, impregnated paper, tape, galvanometers, and control lamps, source of D.C., various tools	5,250
	Total	7,950

Tests on Rectifiers

General Installation

Quantity	Item and characteristics	Total cost in dollars
1	Rectifier laboratory, comprising 4 platforms (1 for the mercury-vapour rectifiers, 2 for the ignitrons), 4 normal type distribution boards, but supplying: 120 V, 50 A, D.C.; 115 V, 80 A single-phase; 115 V, 40 A three-phase	2,400
	Total	2,400

Machines

Quantity	Item and characteristics	Total cost in dollars
2	Rectifiers, three-phase, mercury-vapour, output 50 A, 110 V, D.C.	2,400
2	Ignitrons, capable of operation as rectifiers and inverters:	
	1 for 120 V, 120 A	1,400
	1 for 120 V, 300 A	1,800
12	Rectifiers, selenium, dry, 115 V, 30 A	1,200
	Total	6,800

Quantity	Item and characteristics	Total cost in dollars
	EXPERIMENTS ON SERVO-MECHANISMS	
	General Installation	
1	Laboratory for servo-mechanisms, comprising 6 platforms, used as follows: 2 for tests on the speed control of a D.C. motor by thyratron or ignitron, 2 for tests on the speed control for Ward-Leonard sets, by amplidyne, 2 for the same purpose, by rototrol; 6 feeder distribution boards of the usual type, for supplying: D.C. 120 V, 10 A, 120 V, 80 A, and three-phase A.C., 115 V, 80 A	3,600
	Total	3,600
	Machines	
	Rotary machines	
4	Ward-Leonard sets, 0-110 V, 50 A	4,000
2	Amplidynes, 50 V, 600 W, driven by a three-phase induction motor, 200 V, 2 H.P.	1,600
2	Rototrols, 50 V, 390 W, driven by a three-phase induction motor, 200 V, 2 H.P.	2,000
	Total	7,600

N.B. The measuring instruments and equipment are given in the paragraphs relating to the machine tests, on page 46.

POWER STATIONS

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

Steam engine cycles. Rankine cycle. Superheating and re-superheating. Blowing down. Variation of efficiency with pressure and temperature. Revision of certain aspects of heat transfer and heat exchangers.

Steam generators. Circulation. Control of level. Construction of boilers. Superheaters; superheat control. Economizers and air re-heaters.

Grate hearths. Coker stokers. Chain grates.

Grates burning coal-dust. Laws of combustion. Grinding. Construction of combustion chambers. Sooting-up; cleaning of chimneys. Grates producing molten ash (slagging grates). Fuel-oil and gas-fired installations.

Draught. Chimneys and fans. Dust-precipitating equipment. Elements of the design of boilers. Consumption curves. Feed-water pre-treatment. Scaling and corrosion. Forced-circulation boilers. Automatic control of combustion.

Condensers and the cooling water circuit. Air coolers.

Steam turbines: choice. Control of turbines and consumption curves. Installation of turbo-alternators.

General layout of the generating station and the ancillary installations. Handling of fuel. Ducting. Supply pumps and the control of auxiliaries.

Stand-by power stations. Combined steam and electrical power generation. Storage of heat.

Running costs of generating stations. Economic distribution of loads between units coupled in parallel. Calculation of consumptions. Choice of the main characteristics of the cycle and the materials. Capital charges. Effect of various economic factors. Choice of pressure and temperature. Standardization. Choice of power units.

NETWORKS

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

Electrical Cables and Insulated Conductors

Cables insulated with impregnated paper. Various kinds of underground cable for the transport of power. Electrical operating characteristics, thermal characteristics. Electrical breakdown of cables. Tests on cables at the factory, after laying, under A.C. and D.C. load. Fault location. Laying of cables. Equipment.
Pressure type cables. Oil filled cables. Outline of calculations. Specifications. Accessories.
Rubber-insulated wires and cables. Manufacture and testing of various types. Cables insulated with gutta-percha and balata. Synthetic and substitute rubbers.
Telephone cables. Manufacture, insulation, pairs, quads, assembly, drying, encasing in lead, sheathing of cables for carrier currents. Specifications. Measurement of capacitances and leakage conductances, of unbalanced capacitances, of inductive couplings, crosstalk, the effective resistance of Pupin coils.

Design and Construction of Overhead Lines

Mechanical design of conductors: statics of one span, changes of state; usual hypotheses, ideas about the effects of wind and frost, temperatures reached by conductors; assemblies involving spans in succession (line with rigid insulators, or suspended lines); elements of dynamic phenomena.
Construction and properties of common conductors. Choice of conductors (from the economic point of view, bearing in mind Joule heating, voltage drop, mechanical strength, etc.).
Construction and properties of line insulators. Principal types. Tests. Maintenance.
Supports. Determination of their dimensions, mechanical design (briefly), principal types; arrangements for enabling exceptional loads to be borne.
Accessories (junction boxes, clips, etc.).
Design and construction of lines. Administrative questions. Constructional methods.

Transmission Networks

Study of networks by calculation and by network analysers (calculating boards) (reduced models).
Control of the voltage and the reactive power. Various methods of control, their field of application.
Study of closed networks. Control of the active and reactive power, opening of a loop.
Practical calculation of short-circuit currents using the symmetrical components method. Impedances to be introduced into the calculation.
Dissymmetry in networks; one or two phases cut, transformers constituted by different single-phase elements, etc.
Stability of transmission. Dynamic stability limit, method of calculating stability limits; improvement of stability. Operation in the absence of synchronism in the networks.
Protection of networks. General principles. Different types of relay. Application to machines, transformers, and lines.

Distribution Networks

Main characteristics of D.C. distribution, or of single- or poly-phase A.C. distribution, choice of the distribution voltage and the location of substations, radial and "meshed" distribution.
Description and analysis of the operation of a current-distributing network for D.C. with three wires for two potential differences.
Description and analysis of the operation of a three-phase distribution network, meshed, for 115/200 V, for a large town.
Rural systems: general characteristics, example of the equipment for a rural transformation substation (40/10 kV).

Control of the voltage in distribution networks.

Overall problems relating to the construction of distribution networks: choice of elements, distributive capacity in normal service, protection of apparatus and lines, insulation, building up of fault currents, sustained or transient excess voltages, efficiency and continuity of distribution.

Electrical Equipment of Networks (Power Stations, Main and Subsidiary Substations, Lines, Cables, H.T. Equipment)

Study of systems and their equipment:

General consideration of the make-up of networks. Evolution of systems of distribution, transmission, and generators; interconnexion.

General considerations on the operation of networks. Organization and method of operation. The load dispatching office. Statistics of incidents. Safety of networks and installations.

Practical study of a production and distribution system. Nature of the current. Choice of the distribution potential and the frequency. Voltages in distribution networks, and in transmission lines; voltage drops. Transmission of electric power by H.T. direct current.

General study of schemes of electric power systems: plans for networks, distribution boards, power stations, and transformer stations.

Limitation of electrical disturbances: classification of surge currents, conditions for their elimination or limitation, control of short-circuit currents. Classification of excess voltages, general conception of the insulation of networks, practical co-ordination of insulation, study of the principal devices for protection against excess voltages.

Study of earthing circuits. Classification, general arrangement and construction of earthing circuits; practical study of earths.

General study of H.T. electrical equipment:

Fundamental basis for the electrical design of such equipment.

General study of the heating effect in conductors and at contacts under steady and under fault conditions. Heating with D.C. and with A.C.

General study of insulation. General characteristics and constitution of dielectrics: breakdown and flash-over. Practical study of different forms of electrical discharge in gases: corona effect.

Practical study of insulation. Indoor and outdoor installations; regulation safety factors, fixing of minimum distances. Design and practical construction of post insulators and bushings.

Brief study of mechanical stresses. Special effects of electrodynamic loads: vibrations, arc displacement. Other strains: expansions, and strains due to loads and overloads.

Special study of H.T. switchgear:

General characteristics of electric arcs. Conditions of operation in switches involving arc interruption.

Isolators. Form and manufacture: moving parts, contacts and insulating parts, mechanism of operation.

Circuit breakers using a large volume of oil. General characteristics, operating conditions.

Circuit breakers without oil: those using water, compressed air, pneumatic, shunted arc types, for operation under blast, without air compressing devices.

Modern circuit breakers using small quantities of oil: with an oil jet, operated by a primary arc or by mechanical impulse, orthojectors, convectors, etc.

Special circuit breakers: Deion type, operating on air or oil.

System control

Elements of the theory of control. Construction of a control circuit. Analysis of a canonical control circuit of the first order; references to the circuit for canonical control of the *n*th order.

Speed control for a turbo-alternator set feeding a separate network. Control of the frequency and power in an interconnected network. Information about the characteristics of the consumers (the load).

PRACTICAL WORK

Lines, cables, transmission and distribution of energy:
Study of a dipole and the transmission of active and reactive power components. *Test on a single-phase power transmission line. Measurement of the symmetrical* components of a three-phase system. Short-circuit currents and cyclic impedances in a three-phase line. *Study of the protection of networks and of telephone lines.* Measurement of the constants of a power transmission cable, of a telephone cable, and an H.F. cable. Velocity of propagation, phase change; echo method. Location of faults on cables and lines.

EQUIPMENT

This is indicated in the section on "Electrical Measurements" p. 36, both with respect to the general installation (power lines laboratory) and the equipment and measuring instruments.

HYDRAULICS

COURSE CONTENT *(given only as an example to facilitate the use of the inventories)*

Applied Hydraulics

Hydraulic turbo-machines:
Measurement of the work done by or on a turbo-machine. Tests and measurements relative to hydraulic installations: heights of fall or of rise, discharge rate of the diaphragm and the ducts. Principle of operation of turbo-machines: under optimum, and under any, conditions. Centrifugal pumps: effect of the speed and delivery angles on the form of the characteristics; choice of the speed of a group, special features of screw pumps, and of screw-centrifugal pumps, coupling of pumps. Hydraulic turbines: characteristics at variable aperture. Reaction turbines with total admission, impulse turbines with partial admission. Diagram of specific velocities as a function of the head. Choice of a turbine. Mechanical arrangement and types of turbine installation. Control, accessory units. Study of a design.

Hydraulic installations:
Watercourse conditions. Production and exploitation of head of water. Classification and control of discharges. Management of a region. Equipment of a station, determination of the capacity of reservoirs, equalization by pumping. Different types of falls. Examples of existing installations. Equipment of hydraulic installations. Maximum power and number of turbines. Choice of turbines: coupling. Electrical generators, transformers, equipment for operation and control, intake channels, penstocks and non-rigid conduits. Tests relative to installations. Tests on turbines, and on dams. Rules and regulations. Conditions of execution, costs. Construction of the French super-network.

Operation of channels and conduits:
Energy losses due to the nature and the form of the walls. Diagram for calculating the dimensions of water conduits under pressure. Variable flows. Propagation of plane waves.

Hydraulic Dams

Irregularities of dams. Simple earth, etc., dams. Ski-jump spillways. Arched dams. Reinforced dams, in rock and in earth. Methods of constructing dams.

TELECOMMUNICATIONS

Course Content (given only as an example to facilitate the use of the inventories)

Telecommunications by Wire

Telephony:

Design and construction of the equipment used in telephony. Properties of iron at very low inductions. Make-up of a telephone station: microphone, receiver, systems of signalling, switch. Telephone lines. Propagation of telephonic currents, continuous and coil loading. Telephone relays. Combination of circuits and phantom circuits. Telephony by carrier currents. Conditions permitting telephone lines and power lines to run near one another. Electrolytic corrosion of lead sheathing. Building of telephone lines: overhead, underground, submarine cables. Exchanges, manual, multiple, and automatic. Pre-selectors and line finders. Interconnexion of trunk lines. Rural automatic exchanges.

Telegraphy:

General considerations. Speed and efficiency. Slow, rapid, printing, and multiple apparatus. Baudot's apparatus. Superposition of telephonic and telegraphic communications. Non-rhythmic equipment, Creed system. Transmission of pictures: Belin system.

Telecommunications on Power Lines

The H.T. power line as a channel for H.F. waves. Propagation of steady sinusoidal waves, radiation from the line. Means of coupling an H.F. circuit to an H.T. line. Coupling capacitors. Tuned circuits. Transmission-reception apparatus. Tuned transformers. H.T. blocking circuits. By-passes. Transmission of the carrier wave and the two side-bands. Transmission of a single side-band. Basis of H.F. equipment. Types of telephonic communication: single and two-frequency systems. Coupling of a telephone station to an H.F. equipment and re-transmission. Making connexions. Selective protection of H.T. lines by the wattmeter and by Fitzgerald's methods. Telemetering and tele-adjustment. Components of an apparatus for continuous or discontinuous telemetering.

RADIO-ELECTRICITY AND ELECTRONICS

Course Content (given only as an example to facilitate the use of the inventories)

Wireless Communication

"Closed" H.F. circuits. Circuits with lumped constants: resonators and rejector circuits. Circuits with distributed constants: use of lines as transformers. Wave guides and resonating cavities. "Open" circuits. Radiation from the elementary dipole. Study of practical aerials. Simple aerial, effective height. Aerial oscillating at a harmonic frequency. Combinations of aerials giving directively: reflectors, screens, V- and rhombic forms. Reflectors, horns, and arrays. Propagation of waves into free space. Effects of soil resistance, curvature of the earth, obstacles. Space-ray. Natural and artificial interferences. Transmission. Broadcasting aerials. H.F. oscillator. Modulating circuits. Monitoring of transmitters, quartz monitors. Frequency and pulse modulation. Special features of the production of ultra-short waves. Reception. Wave collectors: aerial and cross-coil aerial. Tuning by simple resonator and by complex systems. H.F., M.F., and L.F. amplification: setting and controlling the amplification. Reaction and feed-back. Various detectors. Frequency changing: description and functioning of a superheterodyne receiver. General considerations on television. Historical summary: electro-optical transducers for transmission and reception; mechanical and electronic methods for image scanning; synchronization and transmission equipment. Brief study of a television receiver. Constituent elements of

a superheterodyne receiver, cathode ray oscillographs, separation of synchronization, line and image signals, scanning. Brief study of the television transmitter: constituent elements of a transmitter for radio broadcasting: pulse generators, production of various signals, transmission and amplification. Vision pick up tubes: iconoscope, orthicon, etc. Industrial, military, educational and artistic uses of television.

Elements of Electronics

The bases of modern physics. Electrical structure of matter; relations between electricity, matter, and energy. Displacement of electrical charges. Structure and classification of atoms; general properties of atomic nuclei. Optical and X-ray spectra. Some consequences and important applications of the fundamental principles: relations between the photon and the atom, between the photon and electrons, wavelength associated with a particle in motion, electron microscope. Spontaneous radioactive transformations. Artificial disintegration of matter. First discoveries due to natural transmutation agents. Artificial transmutations produced by high-speed ions. Developments in the last 10 years: new particles and massive disintegrations. Applied electronic physics: magnetic classification of substances; gaseous ions; ionized electrical fields: line losses from corona effects.

Amplifying Valves

Electron emission. The diode: principle, predetermination of the functioning of a diode. The triode: principle, static characteristics, study of operation in classes A, AB, B and C: limitation of the power output of the tube; effect of internal capacitances. Valves having more than 3 electrodes: principle and functioning of tetrodes and pentodes; valves with variable slope, mixing valves, valves with directed electron beams. Special difficulties arising in high-power valves. Case of very short waves; velocity-modulation valves. Use of valves; practical utilization.

PRACTICAL WORK (is part of that done in the periods devoted to practical work on electrical measurements)

Measurements (electronics)

Plotting the characteristics and measuring the constants of a vacuum tube. Plotting the characteristics and studying the operation of a gas-filled tube. Studying the operation of stabilizing valves. General study, and industrial applications, of cathode ray tubes. Measurements on transient phenomena, use of rectangular signals. Study of a magnetic amplifier. Study of an L.F. amplifier. Study of a D.C. amplifier. Study of the electrometer and the electrometer valve.

Machines (electronics)

Control of the voltage of a dynamo by vacuum tubes. Control of the voltage of an alternator by thyratron. Speed regulation: mototrol. Study of an ignitron.

EQUIPMENT

Measurements: see the section on "Electrical Measurements", p. 36.

Machines

Quantity	Item and characteristics	Total cost in dollars
	Static machines:	
2	Thyratron voltage regulators for alternator	250
2	Vacuum tube voltage regulators for dynamo	1,250
2	Thyratron controllers for D.C. motors (0-240 V, 7 kW)	6,200
	Total	7,700

N.B. The complementary equipment and measuring instruments will be found in the section dealing with machine tests, p. 48.

APPLICATIONS OF ELECTRICITY

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

Electrical Traction

Development of electrical traction in Europe and in the U.S.A. Simple adhesion. Frictional coefficients on starting, and when under way. Axle power for a probable adhesion coefficient. Use of adhesion on braking. Guiding of the rolling stock by the trackways. Non-holonomic returns, parabolic track junctions. Classification of locomotives according to the arrangement of their wheels and bogies. Study of locomotives on curves. Mechanical brakes; various types. General information on Westinghouse brakes. Railway rolling stock. European and American couplings: strength and elasticity. Systems of transmitting the tractive effort to the driving wheels. Motors entirely, partially, or not suspended. Individual and collective wheel drives. General equations of motion of a train: mechanical and electrical equations, heating equations, variation equations. Sequence of conditions in operation. Track resistance. Energy wastage. Traction on D.C. Starting of locomotives. Calculation of the starting resistances of a series motor, construction of stepped resistances, speed control by various means. Regenerating braking. General characteristics of operation. Study of some special regeneration systems. Rheostatic braking. Different methods of use. Overall calculation of braking resistances. Control of braking. Traction on single-phase A.C. Outline theory of a single-phase commutator motor of the compensated series type. Starting, regulation, braking. Various types of single-phase commutator motors proposed for electrical traction. Traction on three-phase A.C. Operating characteristics of three-phase asynchronous motors. Various types of speed control. General layout of three-phase motors. Route tests at 200 km per hour using a three-phase motor (from Marienfeld to Zossen). Single-three-phase traction. Various systems. Transformation of power. General make-up and calculation of the load on traction substations. Power distribution. Contact conductors, third rail. Theory of catenaries. Economic considerations about the use of railways, and the partial electrification of networks.

Mechanical Applications of Electricity

Revision of the mechanical characteristics (torque-speed) of various types of D.C. and A.C. motors. Starting, regulation, braking. Choice of an electric motor. Conditions for stability of control. Industrial applications of the electromagnet: lifting, clutches, brakes, separators. Magnetic chucks. Applications of electricity in mining, and in mineral refining, etc. Winders. Different systems of winding. D.C. drives: Leonard coupling. A.C. drives. Electrification of underground services. Anti-firedamp equipment. Applications of electricity in metallurgy. Reversible and non-reversible rolling mills. Leonard, Kramer, Scherbius couplings. Application of electricity to driving rolling mill ancillaries, hoisting, handling, and machine-tool motors. Contactor equipment. Applications of electricity in the paper and textile industries. Distributed drives. Mechanical and electrical differentials. Control of speed and of pull. Drives for spinning and weaving machinery. Electrical propulsion of ships. Generalities about various types of driving equipment. Piston engines. Internal combustion engines, geared steam turbines. The turbo-electric equipment (A.C.) for the *Normandie*. Auxiliary shipboard equipment: pumps, fans, winches and capstans. Control equipment.

Electrochemistry, Electric Furnaces, Electrometallurgy

Ionization in solution: Arrhenius theory and theory of strong electrolytes. Faraday's law and applications thereof. Secondary reactions, electrolytic oxidation and reduction. Migration of ions; Hittorf's theory. Conductivity of electrolyte solutions. Thermodynamics of e.m.f.'s. Calculation and measurement of contact e.m.f.'s, use of tables. Electrolytic decomposition and polarization.

Accumulators. Theoretical studies (chemical, thermodynamic, and ionic) of the lead and the alkaline storage cells. Various reversible cells. Technical studies: the main characteristic quantities and their variation with various factors. Manufacture and

description of accumulators (plates, accessories, connexions). Applications: stationary batteries, semi-fixed, starting and driving batteries.

Industrial wet-process electrochemistry and electrometallurgy. Electrolytic separations. Production of alkali, chlorine, and its oxygenated compounds. Manufacture of the *oxidation products of certain inorganic substances, and of the reduction products* of certain organic bodies. Electroplating. Refining of numerous metals, extraction of certain metals from solutions of their ores. Composition and general properties of baths; production of certain important metallic deposits.

Electrical furnaces. Classification of types and operating principles. Elements of the design of furnaces: resistance and arc types, and induction furnaces with and without magnetic cores, mixed-type furnaces. Electrical problems connected with furnaces and their installation. Automatic regulation. Furnace technology: refractories, *arches, tapping holes, electrodes, systems of suspension and tilting.*

H.F. heating: principle, and advantages. Theory and applications of H.F. induction heating. Theory and applications of heating by dielectric losses.

Industrial dry-process electrochemistry and electrometallurgy. Manufacture of steel, cast-iron, ferro-alloys, aluminium, calcium carbide and cyanamide. Fixation of atmospheric nitrogen. Chemical application of the electric discharge, and the production of ozone.

Applications of Electricity to Industrial Heat-Treatment

Definitions and determinations of the principal mechanical characteristics of alloys. Tensile, torsional, flexural tests, tests of shearing under stress, of hardness, impact resistance, and fatigue resistance. Composition and structure of metals and alloys. Their relations with mechanical characteristics and physical properties. Graphical depiction of structure in equilibrium diagrams, and experimental demonstration of these structures by metallography. Industrial applications of these structures: essential treatments of metallurgical products with a view to structural modifications. Thermal treatment of iron-carbon alloys, aluminium, magnesium, copper alloys, and of special steels by solution and precipitation of the various elements. Thermal treatment of *alloys having high magnetic properties:* alloys for magnets, ferro-silicon and ferro-nickel alloys having high permeability. Reheat of alloys: in an atmosphere of controlled composition. Laws of heating and cooling. Adaptation of the electrical furnace for thermal treatments: temperature, temperature-control, regulation, time of heating, atmosphere.

Domestic Applications of Electricity

Technical conditions affecting the construction of interior installations. Electrical accessory equipment, conduits, special layouts of secondary circuits. Materials used: usual equipment and tools. Checking of interior installations. Costs and working contracts. Classification and description of domestic electrical apparatus. Apparatus for space heating, water heating, cooking, washing and ironing, household maintenance, refrigeration, water-pumping, and other accessories of a luxury character. General tests on such apparatus: safety, lifetime, operating without causing disturbance to the mains. Special tests: useful power, loss curves, efficiency, stabilization of output.

Agricultural Applications of Electricity

Mechanization of agriculture. Advantages of the electric motor, choice of those to use, conditions of installations of fixed and transportable motors. Electric tilling: determination of preliminary conditions. The rational electrification of a threshing machine.

ECONOMICS AND LEGISLATION

Course Content (given only as an example to facilitate the use of the inventories)

Commercial Exploitation of Power and Tariff Fixing

The economics of electrical power. Study of the origin and development of a *tarif de cuisine* in Paris. Elements of political economy and economic problems posed by

the sale of electrical power. Policy of the sale of electrical energy: policy of private companies, policy of Electricité de France. Determination of marginal costs and of supply rates.

Juridical and Legislative Questions

Generalities about the electricity legislation in France: the laws of 1919 about waterfalls, of 1906 and 1925 about distribution, of 1946 about nationalization. Waterfalls: concessions and permission. Transmission and distribution of electricity: administrative bodies, concessions, wayleaves. French nationalizations. Juridical mechanism of nationalization. Indemnities. The operational balance.

INVENTORY OF EQUIPMENT USED IN THE DIVISION OF RADIO-ELECTRICITY AND ELECTRONICS

ELECTRICAL THEORY

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

Electrical Theory, Electromagnetic Waves

Electricity at rest:
General properties of static distribution of charges. Fundamental field equations. Electrical equilibrium in conductors. Capacitances and mutual inductances. Screens and images. Calculation of capacitances. Case of the two-wire line. Dielectrics. Electrostatic field and induction. Conductors immersed in a perfect and indefinite dielectric. Mechanical forces between electrified bodies. Electrostatic energy.

Electricity in steady or quasi-steady motion:
Direct currents and their magnetic field: fundamental laws. Induced currents and their general electrical field, circuit moving in a fixed field, current fixed in a variable field. Definition and calculation of coefficients of self- and of mutual induction. Fundamental equations of the electromagnetic field for the quasi-stationary states. Forces between conductors traversed by currents. Magnetic energy of currents. Magnetism. Permanent and temporary magnets: fundamental equations. Mechanical actions between magnetized bodies: magnetic energy. Systems of currents and magnetized bodies.

Variable states:
Maxwell's equations: cases of free space and of non-magnetic conductors, and of any medium. Dielectric currents and displacement currents. Retarded potentials. Electromagnetic waves in free space, and in material media. Transparent media. Conducting media: absorption, penetration, and extraction of waves. The principle of relativity and the Lorentz transformation: physical significance of the latter. Invariance of the electrical charge, relativity of the electromagnetic field.

Radiation and propagation into free space:
Electromagnetic energy and radiation. Poynting's theorem and its physical interpretation. Maxwell's equations in curvilinear orthogonal co-ordinates. Waves radiated from a source. General expression for the field, in terms of Bromwich functions. Hertz doublet.

Guided waves:
The simplifying methods and hypotheses adopted by electrotechnics in general. Propagation of currents through bifilar lines, and along a cylindrical wire. Heavi-

side's and Poincaré's theories. Skin effect. Propagation in tubes. General considerations about guided waves. Interference. Phase and group velocity. Special features of H. waves. Co-axial cables. The Heaviside, and the rigorous theory. The co-axial cable considered as a wave guide: secondary and fundamental modes. Cavity resonators: rectangular, cylindrical, and spherical. Natural vibrations. Elementary calculation of damping.

Propagation of Electromagnetic Waves

Propagation at the surface of the earth:

Propagation in a homogeneous non-ionized medium. Effect of the terrestrial magnetic field. Media presenting a plane surface of discontinuity. Vitreous and metallic reflection and refraction. Propagation above a smooth plane surface. Considerations of geometrical optics. Theories of Zenneck, Sommerfeld, Weyl, Norton, and Schelkunoff. Eckersley's phase integral method. Propagation on a spherical earth. Van der Pol's theory. Influence of soil irregularities. Propagation in the standard atmosphere, geometrical representations. Propagation in the real atmosphere: reflection, refraction, and super-refraction; absorption by gases, vapours, rain, snow, etc.

Study of the ionosphere:

Constitution and ionization of the upper atmosphere. Determination of the real reflection height. Causes of ionization of the upper atmosphere. Various layers of the ionosphere. Irregularities in the ionosphere: echo variations, sudden disappearances, magnetic storms. Methods and theories of ionospheric sounding. Determination of the maximum usable frequency, and of the lowest possible usable. Distribution of frequencies in the spectrum. Propagation characteristics of various wavebands. Atmospherics. Methods of recording and various recorders, results. Spatial and temporal distribution of atmospherics.

Electric Circuits, Networks, and Filters

Circuits under variable conditions:

Radio frequency band: its place in relation to other radiations. Free oscillation in a single closed circuit. Charge and discharge of a capacitor through a resistance and inductance. Decrement. Thompson's formula. Charge and discharge through a resistance. Differentiation and integration of simple signals with the aid of a RC coupling. Establishment and suppression of a current in an inductance-resistance circuit. The idea of the time constant: use of circuits with definite time constants. Free electrical oscillation of two electrical circuits, coupled by mutual induction. Solution for the general case, and for two tuned circuits with little or no damping, and for two non-tuned circuits with zero damping. Application to spark transmission. Study of the free oscillation in a single circuit and in two coupled tuned circuits, using the Laplace transformation. Oscillations in a series resonator: transient and steady state. Resonance and resonance curves (amplitude, phase). Various expressions for detuned conditions. Operation of a series resonator. Coefficient of quality Q, loss angle. Introduction of an e.m.f. into a tuned circuit, into a slightly de-tuned circuit, and into a strongly de-tuned one. Parallel resonators, rejector circuits. Behaviour of rejector circuits: magnification, energy exchanges, coefficient of quality Q. conditions for using series and parallel resonators: examples of circuits. Selectivity of a series and of a parallel resonator. Coupled circuits with sustained waves. Magnetic coupling. Operating conditions of the source. Concept of the equivalent circuit. Variations of secondary current. Critical coupling. Various methods of coupling. Variations of the primary current. Application of the theory of coupled circuits to the matching of a circuit to a source. Thévenin's theorem. Examples of application. Voltage gain (two coupled circuits). Step-up and step-down transformers. Power output and efficiency. Selectivity. Systems without reaction of secondary on primary. Selectivity of two coupled circuits for critical and for general coupling. Curves: production of families of universal curves. Wide pass bands obtained with the aid of rejector circuits having displaced tuning. Closed circuits under non sinusoidal conditions. Frequency spectra. Components for closed circuits: assembly and order of magnitude.

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Theory of networks:
Theory of quadripoles. Characteristic impedance and propagation constant. General theorems: Thévenin's, Foster reactance theorem, Bartlett's theorem of equivalence and reciprocity. Energy relations in networks. Transformation of networks. Duality principle. Inverse networks.

Electrical filters:
Principle of filtering. Various types of filters. Fundamental hypotheses facilitating the design of such networks. The dipole (without resistance). Canonical forms. Product and quotient of dipole reactances, their reduced forms. Combination of two dipoles. T- and π sections. Cauer and Jaumann's schemes; image impedance, attenuation, pass and stop bands. Principle of constructing a section knowing the attenuation imposed and the allowable variation of impedance. Application to some examples of low-pass, high-pass, and band-pass filters. Combinations of several dipoles. T-, π-, lattice and bridge sections. Association of successive sections, rules and examples of complex filters. Influence of resistances. Calculation of corrections (methods of Mayer and others). Nomograms (alignment charts). Mismatching, reflection, and interaction losses. Additional terminations. Construction. Normal filters. Quartz filters. V.H.F. filters. Comparison of various systems and their use. Transients. Simple formulae (without proof).

Theory and technique of V.H.F.

Circuits:
Need for new circuits for V.H.F.: their general properties. Wave guides. General equations of guided waves. Description of the fundamental modes of propagation for rectangular, cylindrical and co-axial guides. Effect of irregularities therein. Cavity resonators. Natural frequencies. Equivalent circuits. Description of the fundamental oscillations of resonators of simple form. Methods of study (applicable to wave-guides) of cavities of form not capable of simple calculation. Obstacles in guides. Concepts of coefficient of reflection and of reduced impedance, limit of applicability of these concepts. Description of the properties of some obstacles. Combination of obstacles. Impedance matching, filters, delay lines. Transformer permitting transition from one guided wave to another. Sections of guides having more than four poles. Shunts. Directional couplers.

Valves:
Special features of V.H.F. valves, connected with transit time. General energy relationships. The V.H.F. triode. Velocity-modulation valves. Amplifiers and multipliers of oscillator frequencies. Magnetrons. Travelling wave valves. Crystal detectors.

Measurements:
Frequency standards. Description of some types of wavemeters for V.H.F., and their use. Measurements of impedances and power.

Properties of matter in the V.H.F. region:
Dielectric constant and loss factor. Magnetic permeability. Absorption bands of gases.

Applications of V.H.F.:
Multiplex working and television relays. Electromagnetic detection. Dielectric heating. Acceleration of particles.

PRACTICAL WORK

Circuits and Filters

Study of a series oscillatory circuit, and of a parallel oscillatory circuit. Study of coupled circuits: identical circuits at large voltage increments, circuits with different voltage increment, wide-band filters. Study of an L.F. coupling transformer. Study of an iron-cored self-inductance. Study of electrical filters. Study of L-, π-, and T-

impedance transformers. Transient conditions: response to a unit function spinal, study of rectangular waves. Measurement of the parameters of a piezo-electric quartz crystal.

V.H.F.

Analogue networks; study of fields and resonant conditions. Reflex klystron: Rieke's diagram. Cavities: modes of resonance, measurements of voltage increments. Zero method, hybrid circuits, magic T. Measurements of impedances, obstacles, and iris diaphragms. Dielectric measurements.

EQUIPMENT (for 140 students, divided into two groups)

Quantity	Item and characteristics	Total cost in dollars
Filters		
8	Low-pass filters, 2 for 500 c/s-500, 2 for 500 c/s-5,000, 2 for 1,000 c/s-500, 2 for 1,000 c/s-5,000	320
8	High-pass filters, as above	320
4	Band-pass filters, 1,000 c/s-5,000	160
V.H.F.		
Small equipment		
2	Calibrated attenuators	310
2	Attenuators, cut-off	180
2	Wave-guides, co-axial	120
2	Magic T's	240
2	Non-magic T's	100
10	Guide elements	300
2	Elbows, 90°, H-plan	90
2	Elbows, 90°, E-plan	90
2	T, series	80
2	T, shunt	80
Sources of current		
4	Oscillators, 10 cm, klystron, with power-pack	3,920
4	Oscillators, 3 cm, klystron, with power-pack	3,200
4	Oscillators, U.H.F. calibrating, 250-1,000 Mc/s	1,440
4	Generators, U.H.F., calibrated, 250-920 Mc/s	3,000
Equipment for electronic measurements		
4	Amplifiers, highly selective, for demodulated V.H.F. signals	2,200
2	Wattmeters, electronic, for V.H.F.	1,200
Measuring circuits		
2	Admittance meters, U.H.F.	590
2	Wavemeters, cavity, for 10 cm waves	400
2	Test benches, measuring, for 3 cm waves	3,000
	Total	21,340

N.B. The general installation and the complementary measuring equipment are described in the section on "Measurements in Radiotechnics", p. 62.

BASIC NOTIONS OF ELECTRONICS

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

Identical with that for the division of electricity (see p. 55).

PRACTICAL WORK

Induction furnace: coupling to a load. Heating by dielectric losses. Electronic computing machines.

EQUIPMENT

See the section on "Measurements in Radiotechnics", p. 63.

MEASUREMENTS IN RADIOTECHNICS

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

General considerations on methods and equipment:
Accuracy of measurement and of calibration. Calculation of errors: examples. Construction and use of monograms (alignment charts). Principal methods of measurement: *null*, resonance, substitution and difference. Circuit components: resistances, inductances, capacitors, lines and guides. Characteristics and standards. Sources of current used: sources of D.C. L.F. and H.F. generators. Apparatus of general use: diode voltmeters, peak and minimum voltmeters, thermocouples, cathode-ray oscillographs, amplifiers and attenuators, artificial lines, phase-shifters, bridges, etc.

Measurements at L.F. and audio frequencies:
Measurements of resistance and of insulation. Absolute measurement of potential difference. Measurement of inductance, capacitance, frequency, phase-shift, distortion, constants of insulators and of electrolytes. Impedance bridges. Magnetic measurements.

Measurements of the characteristics of vacuum- and gas-filled tubes:
Plotting of the characteristics and measurement of the parameters of valves on D.C. and on A.C. Plotting of the characteristics of a thyratron on D.C. and on A.C. Plotting the characteristics of various valves: photo-electric cells, rectifiers, U.H.F. tubes, klystrons, etc.

Measurements at H.F. and V.H.F.:
H.F. bridges, the oscillatory circuit used as a measuring circuit. Measurements of resistance, of self- and mutual-inductance, and of capacitance. General measurement of impedances on the Q-meter. Measurements on lines and guides. Measurements of current voltage, and power at V.H.F. Measurement at V.H.F. of impedances by resonance and by stationary waves. Measurement of the constants of dielectrics and electrolytes, and of magnetic materials. Measurements of the characteristics of aerials and radiating elements. Measurements of the characteristics of a quartz resonator.

Measurements of radio frequencies:
Various types of wave- and frequency-meter. Measurements of frequency at H.F., comparison of two frequencies. Measurement of the frequencies of modulated and damped waves. High accuracy frequency measurement.

Measurements on amplifiers:
Measurements of amplitude distortion and transmission delay. Sinusoidal or impulsive waveform. Measurement of the background noise of amplifiers. Plotting stability diagrams.

Measurements on transmitters:
Measurements of power and of the modulation characteristics for sinusoidal modulation. Measurement of the depth of a non-sinusoidal modulation; measurement of distortion and background noise. Measurements of the frequency of a transmitter. Study of frequency spectrum. Experimental determination of electro-magnetic fields and of electron trajectories by analogue methods. Measurements on radiation. Principle, aerials. Measurements of intense, weak, or irregular electromagnetic fields. Plotting of radiation (polar) diagrams. Measurements on interference.

Measurements on receivers:
General considerations, definitions, and equipment. Calibrated generators and artificial aerials. Measurements on input and output signals. Measurements of selectivity and of sensitivity, of fidelity, of distortions and jamming; whistles, radiations, and background noises. Measurements with two signals, and with square waves.

PRACTICAL WORK

Supply:
Study of the circuits of rectifiers and the main types of filtering. Stabilizers of current, D.C. voltage, A.C. voltage.

L.F. Measurements:
Measurements of acoustic frequencies with a cathode ray oscillograph. Measurements of inductance: Maxwell, Hay, and Anderson bridges. Measurements of capacitance: de Sauty and Schering bridges.

H.F. Measurements:
Thermocouples. Non-linear resistors: thermistors and bolometers. Resistance measurement with the Q-meter. Measurements of capacitance and on dielectrics. Measurements of coil characteristics. Measurement of impedances with a Q-meter, with an H.F. bridge, and a double-T bridge. Measurements of radio frequencies. Study of frequency spectra.

EQUIPMENT (for 140 students divided into two groups)

Electricity Supply

This is fed from the substation for the electrical machine tests section, via a four-wire three-phase cable, star connected, giving 190 V between the phases, and 110 V between the phases and neutral.

Quantity	Item and characteristics	Total cost in dollars
General installation		
1	Large laboratory, equipped with 24 standard work benches, 2.5 × 1 × 0.9 m, with drawers and extension flaps	2,880
4	Small laboratories, each having 12 work tables	5,760
	and 8 Faraday cages (2 each)	2,400
	Total	11,040

Electrical Equipment

Each laboratory has a four-wire ring main, capable of being interrupted by remote control from a general distribution board; the circuit-breakers are located at the points

of entry of each feeder line into each laboratory. Current supply points on the walls, located suitably for each load, permit supplies to be made to each bench, each being equipped with a switch and a 10 A fuse (which can with advantage be replaced by a circuit-breaker) and with a series of three input points for three-phase current. Thanks to this simple arrangement, it is sufficient to supply each table with standard 110 V, 50 c/s supply equipment.

Cost of this equipment (distribution boards, "telerupters", auto-transformers, current stabilizers, etc.) is 3,960 dollars.

Apparatus and Measuring Equipment

Quantity	Item and characteristics	Total cost in dollars
D.C. supplies		
60	Switchboards, giving: anode volts, non-stabilized, variable between 0 and 500 V, 150 mA; grid bias volts, 0-90 V; filament volts, 2 × 3.15 V, 5 A, 50 c/s	15,400
30	Switchboards, giving anode volts, stabilized by valves, 0-300 V, 100 mA; filament volts, 2 × 3.15 V, 5 A, 50 c/s	5,700
40	Accumulators, various, lead and cadmium-nickel	240
L.F. *supply* (less than 100,000 c/s)		
20	Oscillators L.F., heterodyne, medium quality (for supplying the bridges), 0-20,000 c/s, 1 W	4,440
10	Oscillators, L.F., heterodyne, superior quality, equipped with calibrated attenuators, 0-20,000 c/s, 0.75-3 W	5,400
10	Oscillators, type RC, low distortion and high stability, 20-20,000 c/s, 2 W	4,200
6	Oscillators, type RC, very high fidelity, large range, 10-100,000 c/s, 0.1 W	3,600
2	Oscillators, type RC, very low frequency, 0.5-5,000 c/s, 0.1 W	1,500
4	Generators for square signals, with attenuator, 50-10,000 c/s	2,200
2	Generators, pulse, 0.1-10μA, amplitude 50 V and frequency 50-5,000 c/s, controllable	1,540
Current sources of H.F. and V.H.F.		
12	Oscillators, calibrated, H.F., 50 kc/s-50 Mc/s	9,600
2	Oscillators, H.F., calibrated, high quality, 16 kc/s-50 Mc/s	3,050
4	Oscillators, calibrated, V.H.F., 8-250 Mc/s	2,880
4	Oscillators, calibrated, frequency modulated	2,720
4	Oscillators, H.F., amplitude-modulated, power 20 W, frequency 1 Mc/s, external modulation, variable degree of modulation	1,320
Non-electronic measuring apparatus		
6	Ammeters, D.C., 1-10 A	240
15	Milliammeters, D.C., 30-300 mA	600
30	Milliammeters, D.C., 10-100 mA	1,200
30	Milliammeters, D.C., 5-50 mA	1,200
20	Milliammeters, D.C., 0.5-1-2-5 mA	800
10	Microammeters, D.C., 10-1,000 μA	500
10	Microammeters, D.C., 3-300 μA	700
4	Voltmeters, D.C., 300-500-750-1,000 V	160
30	Voltmeters, D.C., 100-300 V	1,200
30	Voltmeters, D.C., 3-12-30 V	1,200
20	Ammeters, thermocouple, H.F., 5 of 50 mA, 5 of 100 mA, 5 of 250-500 mA, 5 of 1-5 A rating	1,000
15	Voltmeters, A.C., rectifying, 50-1,000 c/s, 1.5-300 V	600
10	Voltmeters, A.C., rectifying, 50-5,000 c/s, 2-200 V	700
	Carried forward	73,890

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	73,890
8	Wattmeters, output, 5 mW-5 W, 2-20,000	960
2	Wattmeters, output, 0.2 mW-100 W, 2-20,000	520
20	Multimeters, standard, 150 μA-15 A, 1.5-1,500 V	1,000
	Apparatus for electronic measurements	
30	Voltmeters, electronic, H.F., standard, 50 c/s-100 Mc/s, 0.5-150 V	10,500
4	Voltmeters, peak and trough, 0-100 V	800
20	Voltmeters amplifying, L.F., 50-10,000 c/s, 1-300 V	5,000
4	Wave analysers, 20-15,000 c/s	4,160
4	Voltage standards	400
4	Switches, electronic	1,000
4	Distortiometers, bridge	2,400
8	Frequency meters, resonance, 100 kc/s-50 Mc/s	2,400
4	Frequency meters, resonance, 100 Mc/s-1,000 Mc/s	1,200
8	Frequency meters, heterodyne, 50 kc/s-50 Mc/s	3,200
4	Frequency meters, heterodyne, 100 Mc/s-3,000 Mc/s	1,600
2	Frequency meters, heterodyne, with fixed points at 10-100-1,000 kc/s	1,450
4	Frequency meters, L.F., direct reading	1,140
4	Frequency meters, absorption, 0.1-50 Mc/s	600
25	Oscillographs, cathode ray, standard, 9 cm tube	10,000
4	Oscillographs, cathode ray, standard, 13 cm tube, wide band-pass	3,600
4	Oscillographs, cathode ray, standard, 13 cm tube with D.C. amplifier	1,600
4	Oscillosynchronoscopes	4,000
8	Phasemeters, *direct reading, 20-15,000 c/s*	4,000
8	Q-meters, usual type, 50 kc/s-50 Mc/s	8,000
4	Wobbulators	1,200
	Test circuits	
10	Resistance boxes, decade, low time constant, 1,111 Ω	750
30	Resistance boxes, decade, low time constant, 11,110 Ω	2,490
20	Resistance boxes, decade, low time constant, 111,110 Ω	2,140
10	Resistances, decade, 100,000 Ω	210
10	Resistances, decade, 1 MΩ	440
100	Resistances, calibrated, H.F., between 1 and 100 Ω	850
50	Rheostats, potentiometric, 1,000-5,000 or 10,000 Ω, 10-15 W	350
10	*Loading resistance boxes, 50,000 Ω, 10-15 W, variable in steps of 500*	150
10	Capacitance boxes, decade, 1, 11 μF, and 1,000 pF, variable	3,400
10	Capacitors, standard, 1,000 pF	2,500
6	Capacitors, standard, 100 pF	1,500
10	Capacitors, calibrated, various ranges: 50-100-250-500-1,000 pF	500
2	Inductances, boxes, 1 H maximum, 3 decades	460
2	Inductances, boxes, 10 H maximum, 3 decades	600
2	Inductances, variable, 20-50 mH	130
60	Rectifiers, dry, various types	180
2	Inductances, variable, 20-500 mH	130
30	Transformers, instrument, double screen, 50-5,000 c/s	600
4	Transformers, instrument, double screen, 2-500 kc/s	80
12	Transformers, coupling, L.F., with median tapping, various ratios	180
10	Attenuators, calibrated, L.F., attenuation of 100 db per band of 0.1 db, impedance 600 Ω, frequency 50-100 kc/s	2,750
4	Attenuators, H.F., 100 db, 50 Ω, 50 Mc/s	800
4	Impedance bridges, universal, L.F.	1,200
4	Impedance bridges, H.F., 0.5-60 Mc/s	1,900
4	Impedance bridges, H.F., 50 kc/s-5 Mc/s	1,940
2	Impedance bridges, V.H.F., 10-165 Mc/s	770
4	Admittance bridges, double T, 0.5-30 Mc/s	2,080
	Total	173,700

TRANSMISSION AND RECEPTION

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

Transmission, Design and Construction of Transmitters

Oscillators

Self-oscillators. Practical treatment under steady state conditions. Stability. Application to Hartley and Colpitts circuits. Very stable oscillating circuits: Franklin, E.C.O. (electron-coupled oscillator, circuit with centre tap on the cathode), dynatron. Quartz oscillators.
Very short-wave oscillators. Resonant line oscillators with "classical" valves, co-axial line oscillators with disc electrodes in the valves. Special wide-range oscillators: cylinder, horn.
High-power oscillators for industrial use: for H.F. induction heating, and heating by dielectric losses.

H.F. amplifiers and multi-stage amplifiers

Design of a multi-stage H.F. amplifier: various powers, efficiency, etc. Selective power amplification under class B and class C conditions. Balanced or push-pull circuit, effect of symmetry. Application of symmetrical neutrodyning. Various neutrodyne circuits for single valves.
Design of an oscillating anode circuit and the various methods of matching to the input. Design of grid circuits.
Frequency multiplying.
Oscillatory circuits with distributed constants.
Amplifiers with earthed (grounded) grids: amplifiers with cathode loads.
H.F. multi-stage amplifiers. General considerations which decide the different functions and the number of H.F. stages. Monitoring. Frequency multiplication. Manipulation, adjustment, and measurements.
Ancillaries; cooling, protection, mechanical controls.
Layout of the components in a transmitter. Complete circuit diagrams for multi-stage H.F. amplification, sketches and photographs.

Modulators, amplifiers and L.F. amplifier stages, modulated H.F. amplifiers

Design of an L.F. amplifier stage: power, distortion, frequency response curves. L.F. amplifiers of various types: resistance, choke and transformer coupling. Balanced circuits under class A, AB, and B conditions. Dimensioning of the various components. L.F. multi-stage amplifiers. General considerations determining the number and functions of the L.F. stages. Selection of couplings and the modes of operation. Overall characteristics of distortion and background noise. Design of a complete L.F. multi-stage amplifier.
Negative feedback: application to an L.F. stage amplifier, control and measurement.
Amplitude modulation at telephonic frequencies: anode, control grid, and suppressor grid modulation. Design of the modulated stage and of the modulator.
Amplitude modulation and amplification of the H.F. wave modulated under class B conditions, high efficiency methods. Doherty, Chireix, etc., systems. Single side-band systems.
Amplitude modulation by signals with frequencies in the vision frequency range. Characteristics imposed on amplifiers under sinusoidal and transient conditions. Video stages, H.F. and L.F.
Frequency modulation. Production and amplification of signals modulated in frequency and phase. Specifications for the L.F. stage amplification. Pulse modulation. Pulse time modulation. Multiplex systems, "scrambling" (code telephony).
Telegraphic operation.

Reception, Design and Construction of Receivers

Signals to be received, output level. Fundamental requirements and constituent elements of a receiver. Sensitivity. Limitation of interferences. Noise factor.

Addition of noises. Selectivity. Band-pass required. *Frequency and phase distortion*. Principal selective systems, under steady and transient conditions: the simple resonator, chains of resonators and transformers tuned or de-tuned. Compromise between selectivity and fidelity. Protection against interferences and jamming.

Wave collectors. Reciprocity in transmission and reception. Simple aerial. Anti-interference aerial, various directional and frame aerials. Networks and feeders. Artificial aerial for tests of receivers.

Input circuits. Direct and indirect coupling. Discussion of the coupling giving the maximum voltage, power, or signal-noise ratio. Case of de-tuned primary. Very high frequencies.

H.F. *amplification. Application of the formula for the gain* of a stage to various types of amplifiers: capacitance resistance couplings, couplings by tuned circuits, by transformers tuned or otherwise, circuits with grounded grids or anodes. Various types of coupling between stages. Comparison of a triode with a pentode. Case of V.H.F. circuits with lighthouse valves and co-axial tubes.

Detection. Various types of detectors. Effect of the time constant, and of the input impedance. Simultaneous action of two signals on a detector. Demodulation of a weak signal by a strong one. Appearance of sum and *difference frequencies*. Background noise in detectors. Detection of a frequency modulated wave: discriminator. Detection of pulses.

L.F. amplifier for telegraphy or telephony. Various circuits: resistance, aperiodic transformer, etc. Output (power) stage, balanced (push-pull) circuit; output transformer. Special amplifiers for television and radar.

Frequency changing. Principle. Formulae for conversion conductance. Frequency changing by detection of superimposed voltages, and by mixing in a multigrid valve. Heterodyne and superheterodyne. Local oscillators, stabilization. Amplifiers for intermediate frequencies. Selectivity before and after conversion. Background noise and interference. Choice of the intermediate frequency. Single control *(ganging), alignment, calculations for padders and trimmers*. *Double frequency* change.

Feedback. General formula. Effect on gain, stability, distortion, input and output impedance, and noise. Nyquist criterion. Use of feedback. Maintenance of oscillations. Negative feedback: its possibilities and limitations, and use. Super-regeneration. Various modes.

Manual and automatic gain control (simple, amplified, delayed); adjustment of tuning (indicators), of sensitivity, selectivity, fidelity, and tone quality.

Radio Broadcasting

Revision of general considerations concerning L.F., H.F., and power amplifiers. Special amplifiers for various kinds of modulation. Modulation by phase-shifting.

Qualitative study of transmission equipment.

Qualitative study of the installations associated with a transmitting station: transmitters, power supply, hydraulic installation, aerials. Simultaneous coupling of two transmitters to one aerial.

Organization and operation of a transmitting station.

External technical qualities of a transmitter: power, frequency, unwanted radiations.

Synchronization of transmitters.

Present trends in the development of high-power transmitters.

Television

History of the progress of television: electro-optical transducers; equipment for scanning, synchronization and transmission.

Response of the eye to television images. Photographic aspect of the image, flicker, scanning of objects in rapid movement, reproduction of colours.

Frequency bands required for the transmission of the image. Transmission of the *continuous component* and of low frequencies. Importance of the time constants of the various circuits. Various types of distortion.

Characteristics of television systems with interlaced lines.

The receiving cathode-ray tubes: tubes with electrostatic focusing, tubes with magnetic focusing. Recent developments.

Study of the television receiver. Various forms of signals adopted. Various types of receiver. Constituent elements of a superheterodyne television receiver: H.F. amplifier, change of frequency, M.F. amplifier (sound and vision), detection, L.F. and video amplification, cathode-ray tube, re-formation of the continuous component, separation and amplification of synchronization signals, and of line and image signals, scanning, power supply.
Television cameras. Application of photo-electric emission and of secondary emission to television: secondary emission cells, electron multipliers, electron telescopes, monoscopes, iconoscopes, orthicons, etc.
Study of the television transmitter. Various types: radio broadcasting transmitter, aeroplane transmitter, outside broadcasting transmitter, transmitter for guided missile. Constituent elements of a television transmitter: pulse generators, production of various signals, transmission and amplification of signals at video frequency, transmission of low frequencies.
Scanning systems used in film television: various systems.
Colour television, television in relief.
Industrial, military, educational, and artistic applications of television.

Lines and Aerials

H.F. lines

Fundamental equations of lines: lossless and lossy lines. Physical significance of primary constants. Definition and physical significance of secondary constants, and discussion. Cases of bifilar and co-axial lines.
Study of lines loaded at the end. Lossfree lines: distributed impedances, study of the voltage and current, coefficient of stationary waves (coefficient of reflection). First simple applications: quarter-wave transformers, rotating joint, "duplexer" system used in radar, etc. Lossy lines: impedances, voltages and currents, reflection coefficient, power transmitted. Application to resonant and anti-resonant lines.
Impedance diagrams (cartesian and polar) and their use.
Application to problems of matching. Matching by stubs. Case of a single stub: algebraic and graphical solution. Case of two or three stubs. Principles of measurements on metric and decimetric waves.

Aerials

Fundamental problems raised by the study of aerials. Classical theory of the cylindrical transmitting aerial. Some references to exact theories.
Calculation of the field radiated at large distances, by vector methods. General theorems. Some important examples. Particular case of directional systems. Power radiated and radiation resistance. Graphical calculations. Some important examples. Definition and discussion of the concept of gain. Input impedance. Hallen's theory. Impedance curves. More approximate methods of calculation. Applications: matching and width of band.
Coupling between aerials. Mathematical expression of the problem: calculation of impedances, self and mutual, by the classical method, curves representing the results. Some important examples.
Receiving aerials. Mathematical expression of the problem: application to the case of a thin dipole. Reciprocity between transmitting and receiving aerials: gain, polar diagram, etc.
Broadcasting aerials. Vertical aerials for waves in the hectometric band. Study of earths and anti-fading.
Directional aerials for short waves. Description of various classical types of directive networks. Study of the rhombic aerial.
Wide band aerials. Various types used in television.
Special study of equipment used for V.H.F. reflectors, horn radiator, dielectric aerials, lenses, slotted guides.

Radiodirection finding and Radionavigation

Radiodirection finding
Direction finding with a rotatable coil (loop aerial). Theory of the loop aerial. Antenna

effect. Sense finding. Accuracy: instrumental errors, site and propagation errors. Description of various types.

Radiodirection finding with fixed loops. Principle and theory: Bellini-Tosi systems; seekers, errors caused by this system.

Radiodirection finding without night effect. Pulse radiodirection finding. Adcock system, and its errors. Description of various types.

Developments in radiodirection finding equipments. Robinson, homing, and automatic types. System with additional modulations, systems with cathode ray indicator having automatic orientation, and with two-phase currents.

Radiodirection finding on short and ultra-short waves.

Use of radiodirection finding.

Radionavigation

Radionavigation over long distances. Altimetry: altimeters operating on frequency modulation, and on pulses. Ancillary measurements: measurement of the drift by using two altimeters, detection of obstacles. Description of some systems: Consol, Noveglobe, Loran, etc.

Radionavigation over medium and short distances. Decca and Gee systems. Radio beacons of various types: four-axial for M.F., two-axial for V.H.F., omni-directional, rotating beam, etc. Equipment for measurement of distance.

Approach aids. Ground radar, V.H.F. position finders, equipment on board the aircraft.

Landing aids: SBA, ILS, and GCA systems. Guiding by centimetric and decimetric waves. (BABS, Sperry).

Radionavigation in time of war. GH, Sheran, and Oboe systems.

Glimpse of the future of aerial navigation and traffic control.

Design and Construction of Radar Equipment

Radar equations: in free space, in the presence of indirect paths. Remarks on the validity of these equations: radiation factor for the object, estimation of signal detectable against a background of noise.

The transmitter. Pulse generator and modulator. *Use of artificial lines: charge and* discharge. Description of the various types of oscillators.

Aerials and associated circuits. Gain and directivity of aerials, various scanning and balancing methods. Wave guides and flexible joints. T.R. and anti-T.R. circuits.

The receiver. Optimum band-pass. Various parts: H.F., M.F., video. Local oscillator. Automatic frequency control. Protection against "dazzling". Various types of indicators, with the corresponding scanning circuits, synchronization.

Elimination of echoes (from fixed objects).

Construction of radar equipment. Description of some standard equipments. Construction and use of transponders: radar and the identification of friends and enemies; responding rangers and interrogating receivers, special circuits.

PRACTICAL WORK

Transmission

Oscillators:

Energizing and synchronization of a self-oscillator. Study of the maintenance of oscillations in feed-back oscillators (R.C. oscillators, Wien bridge and phase-shifting oscillators). Multi-vibrators, pulse counters. Blocking oscillators.

Amplifiers:

Voltage amplifiers, L.F. and video: study under sinusoidal conditions, and when dealing with pulses. H.F. voltage amplifiers. L.F. power amplifiers: class A and AB. H.F. power amplifiers: classes B or C, and of modulated H.F. amplifiers. Influence of the grid-anode capacitance. Amplifiers with earthed grids and cathode followers. Study of the stability of a negative feed-back amplifier. Nyquist-Bode criterion correcting networks. D.C. amplifiers. Amplifiers with distributed constants. Current amplifiers for magnetic scanning. Magnetic amplifiers. Noise in amplifiers.

Modulation and detection:
Detection of a sustained wave: diode, grid, and plate detection. Detection of an amplitude-modulated wave with a diode; distortions. Detection of a frequency-modulated wave; discriminators. Plate and grid modulation. Frequency and phase modulation, reactance valves. Pulse modulators.

Reception

Receivers:
Input and reception circuits. Change of frequency. Automatic gain control. L.F. negative feed-back. Alignment of a receiver. Measurements on receivers: sensibility, selectivity, fidelity, etc.

Lines and Aerials

Lines:
Artificial line: current, potential, phase, and impedance. Matching a line to a load. Transient conditions on lines. Delay lines.

Aerials:
Distribution of current and voltage in a rectilinear aerial. Input impedance of a vertical aerial fed at the base. Input impedance of a symmetric dipole in the presence of an interference. Yagi aerial, two dipoles fed. Linear networks: primary and secondary diagrams. V.H.F. aerials, arrays, slots, reflectors and lenses.

EQUIPMENT (for 140 students in two groups)

Quantity	Item and characteristics	Total cost in dollars
Transmission		
Sources of D.C.		
4	Distribution boards, giving anode potential, 0-2,000 V, 250 mA, filament volts 2 × 6.3 V, 10 A, 50 c/s	1,440
Sources of current at H.F. and V.H.F.		
10	Oscillators, H.F., instrument, 0.1-30 Mc/s	3,300
6	Oscillators, V.H.F., instrument, 5-500 Mc/s	1,860
Electronic measuring equipment		
20	Amplifiers, instrument, L.F., selective, detectors for bridges	5,000
2	Modulometers	800
Reception		
8	Communication receivers, 100 kc/s to 50 Mc/s	2,800
4	Commercial receiving sets	1,000
2	Panoramic receiving sets	1,200
Lines and aerials		
2	Co-axial measuring lines, with sonde and accessories, 300 to 3,000 Mc/s	600
1	Set of co-axial equipment, various elements	400
1	Measuring line, V.H.F., going up to 10,000 Mc/s	500
	Total	18,900

N.B. Complementary apparatus is listed in the section dealing with "Measurements in Radiotechnics", p. 63.

ELECTRON TUBES AND GENERAL EQUIPMENT IN THE RADIO-ELECTRICAL INDUSTRY

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

Present Trends in the Radio Industry

Equipment

Basic materials: non-ferrous metals, ferrous metals, insulating materials, etc. Use in radio. Mechanical and electrical properties. Specifications and tests.
Methods of manufacture and machining. References to metal working.
Procedures and rules for assembly. Controls. Specifications and tests.
Construction of a commercial model. The main sections. Methods of organizing and co-ordinating work.
Technology of electrical power supply. Operation, circuits, predetermination, specification and tests: of D.C. sources (batteries, accumulators, rotary converters, H.F. and L.F., H.T. and L.T. rectifiers, of small and large power; filtering of rectified currents: determination, capacitors, and self-inductances); of A.C. sources (alternators, transformers, interrupters); pulse sources (transformers and inductances).
Regulating equipment for currents and voltages. Principles, circuits, operation, predetermination, specifications and tests for mechanical and electrical regulators.
L.F. technique. Predetermination, specification and tests of resistances, capacitances, self-inductances and transformers. Current sources: microphones, laryngophones, pick-ups, readers, photo-electric cells. Receiving apparatus: headphones, loudspeakers, recorders, indicators, magnetic discs, tape and wire.
Radio technique. Theory of circuits, effect of frequency, voltage, and power on operation. Predetermination. Specifications and tests for resistances, fixed and variable capacitors, and self-inductances. Construction of specifications and tests for coils, frame aerials, lines, Kolster currents, wave guides and resonating cavities.
Special technique for V.H.F. Construction and determination of resistances and capacitors.
Various mechanical components: contactors, interrupters, switches, relays, screens, and scales, divided scales.

Physical Study and Construction of Electron Tubes, Vacuum Technique

Thermionic phenomena: general law. Contact potential difference. Cold emission, secondary emission.
Vacuum diodes. Fundamental parameters of a rectifying diode, and of a detecting diode.
Triodes: General theory. Equivalent diode. Fundamental parameters. Grid currents. Input and output admittances. Factor of merit.
Tetrode: increase of the internal resistance, reduction of the feedback due to the grid-anode capacitance.
Pentodes: general characteristics. Virtual cathodes. Multiple valves. Conversion conductance.
Physical limits of amplification: background noise. Comparison between the various tubes with regard to noise resistance. Limits when the frequency increases. Control power. Form of the current in the external circuit. Diminution of efficiency.
Gas-filled tubes. Hot- and liquid-cathode diodes. Ignitrons. General description of the relevant fields of application.
Thyratrons: characteristics and general parameters. Transitors.
Vacuum. Reversed grid current: various causes. Pressure limits attainable. Various vacuum pumps. Degassing. Getters.
Cathodes. Various types and their production. Design of cathodes.
Preliminary ideas about the design of valves. Amplification factor. Internal resistance. Power which can be dissipated. Problems raised by energy dissipation on cathodes, grids, and anodes.
The various materials used in tubes. Elements of construction.
Electron optics: generalities. Design of the beam track. Analogies with geometric optics. Thin electric lenses. Thick electrical systems. Conjugate points, focal surfaces and focal lines. Generalities about aberrations.

Magnetic electron optics: general laws of the formation of images. Thin magnetic lenses. Thick magnetic systems. General characteristics of the parameters encountered in magnetic electron optics.
Electronic instruments: electron microscope, electronic analyser, mass spectrograph. Cathode-ray tubes: general theory. Various optical systems used. Screens. Adaptation to various uses.
Photo-electric cells: general theory. Special tubes for television; iconoscopes; orthicons. Electron multiplying tubes in general.

Operation and Use of Valves

Diodes:
General considerations as to their behaviour, limits of use. Use of diodes, rectifying characteristics. Linear and square law detection. Rectifying of input currents: one or two alternatives. Filter sections. Examples of static and dynamic characteristics. Demodulation. Principle and characteristics of gas-filled diodes.

Triodes:
Generalities. Secondary emission. Fundamental equation and characteristic coefficients. Equivalence theorem. Study of the behaviour in the straight region of the characteristics for various types of load impedance. Operating conditions. Description of various conditions, and of various distortions (amplitude, frequency, phase). Behaviour under class A conditions. Theoretical behaviour in the idealized network on ohmic load, maximum useful power. Behaviour in real networks on ohmic load, on resistance reflected by an ideal transformer, and on a tuned oscillator circuit. Calculation of the amount of distortion. Correct positioning of the dynamic characteristic in the Kellog network. Behaviour under class B conditions. Study of the class B high frequency amplifier with an oscillating circuit in the anode circuit. Dynamic characteristics of the idealized circuit. Behaviour under class AB, low frequency, for real characteristics. Useful power and distortion. Push-pull and push-push systems. Behaviour under class C conditions. Idealized network, dynamic characteristics, power and efficiency. David diagrams. Practical problems. Behaviour on real characteristics. Practical operating conditions. Grid control power. Some considerations relative to the anode oscillating circuit. Effect of interelectrode capacitances. Calculation of the acutal amplification. Equivalent circuit for the valve, for the anode load. Possibility of excitation of oscillations and neutrodyne circuits.

Tetrodes and pentodes, beam valves:
General study of multi-electrode valves, examples of characteristics. Valves with variable slope. Intermodulation. Hum modulation. Comparison of triodes and pentodes in the L.F. and H.F. amplification of voltage and of power, for various couplings between one stage and the next. Improvement of amplification by negative feed-back. Numerical applications.

Valves for U.H.F.:
Special considerations relative to their operation: input admittance, effect of interelectrode capacitances and of the transit time of the electrons. Current fluctuations. Various sources of noise.

Oscillators:
General considerations. Limiting conditions for oscillation. Factors affecting the frequency and the stability of the oscillations. Stable circuits. Quartz oscillator. Monitors. Practical circuit diagrams for oscillators. Comparison of sinusoidal oscillations and those of relaxation. Van der Pol's algebraic study and graphical interpretation. Generators of relaxation oscillations. Multi-vibrators. Over-coupled oscillators: physical study of "blocking oscillator". Synchronization and division of frequency. Coupling of a passive circuit to a self-oscillator. Effect of variation of the tuning in the circuit. Stability of oscillations. Phenomenon of pulling into tune.

Amplitude modulation:
Relations between the mean and peak power of the carrier wave. Band required

for transmission. Overmodulation. Study of anode modulation, of modulation by the control grid and by the suppressor. Comparisons between the various powers brought into action, and of the efficiencies around the modulation cycles. Coupling of the modulator to the stage modulated. Modulation improvement. Amplification of an H.F. wave modulated by a class B amplifier: idealized and actual network. Arrangements for compensating the load variations on the preceding stage: "buffer" valves, pre-amplifier with cathode bond.

PRACTICAL WORK

Vacuum Tubes and Electron Optics

Plotting the electrostatic field with the electrolytic tank. Plotting of electron trajectories. Determination of the characteristics of a triode with directly heated cathode, of a triode and a pentode with indirectly heated cathode, of a dynatron and transitron valve, and of photo-electric cells. Measurement of parameters of vacuum tubes: Appleton's method, Miller's method. Input impedance of valves. Transistor amplifiers.

Gas Filled Tubes

Determination of the characteristic of a thyratron; use of a thyratron as a relaxation oscillator. Thyratrons on D.C., types of control, inverters. Thyratrons on A.C., rectifiers, control of motors. Study of an ignitron.

EQUIPMENT

See the relevant part of the section on "Measurements in Radiotechnics", p. 63.

COMMUNICATIONS

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

Theory of the Transmission of Information

Concept of information. General layout of a communications system.
The time factor in the transmission of signals: periodic functions, line spectra; information functions, band spectrum and various other spectra; noise and error functions, uniform spectrum of noise of molecular origin.
Calculation of the information-load capacity of an electro-mechanical circuit.
The Hartley-Shannon-Wiener fundamental relationship and its consequences.
Fundamental principles of frequency modulation.
Brief history. Present field of use.
Theoretical bases: instantaneous frequency, modulation and deviation of phase and frequency. Relationships defining and interrelating them. Spectra of signals frequency modulated by a sinusoidal signal.
Composition of a receiver. Linear chains. Non-linear components: limiter, discriminator. Effects of jamming, noise and interference. Calculation of the signal noise ratio before the limiter and at the output from the receiver.
Principle of radiotelephonic code systems.
Sampling in time and amplitude. Signal noise ratio. Application to code systems of the Hartley-Shannon-Wiener relationship.

Communication by Wire

Telephony:
Analysis of the human voice. Properties of the ear. Frequencies and power used in telephony.

Prepayment telephone apparatus. Transmitter and receiver. Dialling device. Layout of prepayment stations. Various pieces of equipment making up the ensemble of telephonic equipment.
Telephone lines. Theory of propagation on these lines. Loaded lines. Repeaters. Construction and supervision of lines. Protection of lines against the effects of atmospheric electricity and power transmission lines.
Telephone switching equipment. Manual and automatic exchanges.
Composition of a telephone network. Universal service.

Telegraphy:
Scheme of a telegraphic channel. Propagation of telegraph currents along a long line. Operation of the receiving apparatus, association of a line and a receiver. Modulation. Telegraphic speed and efficiency. Morse and derived equipments: Hughes, Baudot.
Improving the efficiency of telegraph lines: duplex, diplex, double current, automatic, and multiple transmission.
Telegraphic transmission over telephone lines: harmonic, ultra- and infra-sonic, and superphantom.
Non-rhythmic teleprinters: Creed system.
Telegraphic exchanges.
Submarine telegraph cables. Composition and manufacture. Laying of cables. Use of long, and medium long, cables. Faults and repairs.

Organization, Use and Regulation of Radio-communications

Radiotelegraphy:
Various methods of exploitation: duplex, alternating (two-way communication) in air, in a network. Various codes used.
Morse code equipment. Automatic equipment: perforator and transmitter.
Spectrum of signals. Characteristics of the output signals from receivers, and their return through the Bureau Central des Radiocommunications (BCR) (Central Radiocommunications Office).
Control of transmitters: in frequency and in amplitude.
BCR receiving apparatus. Undulators.
Use of teletype, Baudot, Verdan, Hell-Siemens apparatus.
Technical operation of radiotelegraphic links, and organization of the BCR.

Radiotelephony:
Essential devices for connecting a subscriber to the circuits going to the radio transmitter and receiver.
Blocking and unblocking devices. Delay lines. Modulation control. Arrangements for preserving secrecy.

Radiotelephotography:
Principle. Time and frequency modulation. Synchronization and phase-matching. Description of transmission and reception equipment.
International organization of radiocommunications.
International conferences, permanent organizations. Legislation.

Radiocommunication in the Public Services

General considerations concerning radiocommunications:
General description of systems of transmission and reception used on the different wavelengths for obtaining a satisfactory standard of communication in spite of difficulties encountered in radio links.
Minimum field strength for the different waves and the different services.
Practical calculation of the characteristics of links on the different wavelengths. Preliminary calculation of the signal-noise ratio on these waves.

Communication over long distances:
General organization: transmission centre, reception centre, central office.
Band used. Form of the signals. Permissible distortion.
Transmission and reception on long waves. Description of a transmitter-receiver system for handling a large flow of communications.

Transmission and reception on short waves. Telegraphy by conventional methods, and by frequency displacement. Telegraphic diversity. Permissible distortion on Morse, and on teletype.
Telephony by the conventional method, and by using a single side-band. Diversity with a single side-band. Description of a transmitter-receiver system, for operating on a single side-band.

Communication over medium distances using short and very short waves:
Multiplex communications by frequency modulation. Statistical effect and its influence on the level of modulation and the signal-noise ratio. Special amplifying and discriminating circuits.
Description of a co-axial cable for frequency modulation, and containing relay stations.
Telecontrol (remote control), reporting of faults, maintenance equipment.
Multiplex communication using pulses. Statistical effect. Pulses modulated in time, in displacement as a function of amplitude and of the frequency of modulation; coded pulses. Anti-interference properties of these systems and arrangements brought into operation in the various cases.
Description of a transmission-reception installation with relay stations.
U.H.F. components used, depending on the frequency.

VARIOUS APPLICATIONS

COURSE CONTENT *(given only as an example to facilitate the use of the inventories)*

Application of Piezo-electricity to Transmission

History of piezo-electricity.
Basic laws. General equations. Propagation of waves in crystals. Vibrations of a thin crystal slice perpendicular to the electrical axis.
Influence of temperature on the frequency. Calculation of temperature coefficients. Various cuts having no temperature coefficient: AT, BT, CT, DT, and GT crystals. Use of quartz resonators for frequency stabilization. Electrical circuit equivalent to a crystal slice. Measurement of equivalent constants.
Maintenance of oscillations in a quartz lamina. Various circuits. Control of the crystal frequency. Application to the construction of band filters. Frequency selectors.
Cutting and preparation of crystals. Determination of the optical axis. Experimental determination of the binary axes using X-rays.
Various applications: thermostats, quartz clocks, ultrasonics.

Applications of Radio-waves in the Army

Applications of Radio-waves in the Navy

Applications of Radio-waves in Aviation

ELECTROTECHNICS AND MISCELLANEOUS

COURSE CONTENT (given only as an example to facilitate the use of the inventories)

Applied Electrotechnics

Various materials used: conductors and insulators. Various windings. Magnetic circuits. Ordinary, and automatic, equipment.
Power sources: dynamos and alternators. Sub-station (kiosk).
Nature of transmission: lines and transformers.

Apparatus for utilization: D.C., induction, and polyphase commutator motors.
Tariff fixing of electrical energy.
Safety of electrical installations.

Electrical Measurements

Ratio of the C.G.S. units. Electrostatic and magnetic systems: ratio of units. Non-rationalized and rationalized Giorgi systems.
Studies of moving coil galvanometers. *Critical condition (of damping)*, pseudo-periodic system, optimum damping, damping used in practice.
Voltage and current sensitivities, practical sensitivities. Limit of sensitivity: Brownian movement. Ballistic galvanometer: sensitivity in the critically damped condition, practical sensitivity in coulombs. Applications to the measurement of capacitance and mutual inductance, of a flux linkage, of the electrical and mechanical constants of a galvanometer, the logarithmic decrement, and the period.
Moving magnet galvanometer.
Oscillographs and vibration galvanometers. Voltage and current resonances. Formal identity of behaviour of mechanical systems with electrical circuits. Optimum conditions. Sharpness of resonance.
Ammeters and voltmeters of various types. Temperature correction. Universal shunts.
General considerations concerning electrodynamic instruments.
Instruments using properties of rotating fields. Revision of the theory of symmetrical components. Ferraris induction wattmeter.
Effect of A.C. Measurement of loss angle for dielectrics, the hysteretic angle of phase advance for magnetic materials. Principle of Epstein's method for measuring iron losses.
Irond-cored inductances.
Moving-iron ammeters and voltmeters. Properties of nickel-iron alloys. Permeability of a coil under the simultaneous action of a D.C. and an A.C. field.
Potential and current transformers. The transformer conceived as an impedance matching device.
Metering of electrical energy.

Tests on Electrical Machines

D.C. *machines:*
Generalities: induced e.m.f., windings, armature reaction, commutation.
D.C. generators. Internal characteristics; various methods of excitation: external characteristics. Use.
D.C. motors. Principle, torque, starting, speed regulation, characteristics. Use. Losses and Joule heating. Efficiency, by separating the losses, and by Rayleigh's method. Ward-Leonard sets. Amplidyne. Rototrol.

A.C. *machines:*
Iron-cored self-inductances used in tests on machines.
Transformers. Principle. Kapp diagram. Coupling in parallel. Losses and efficiency. Auto-transformers. Scott and Leblanc transformers.
Alternators. Principle. Characteristics. Potier's method. Efficiency.
Synchronous motors. Principle. Regulation of the active and reactive components of the power consumption. Connexion of machines to a network.
Rotary converters. Principle. Comparison with motor generator sets and with rectifiers.
Polyphase induction motors. Principle, torque, slip, circle diagram. Squirrel cage rotor. Dynamic braking, and as a generator. Selsyn transmission.
Single-phase induction motors. Starting. Comparison with polyphase induction motors.
Single-phase and three-phase commutator motors. Frequency changer.

Servo-mechanisms:
Same course content as for the division of electricity.

Electro-acoustics:
Same course content as for the division of electricity.

Telecommunications on power transmission lines:
Same course content as for the division of electricity.

PRACTICAL WORK

Electrical Measurements

D.C. Wheatstone bridge. Sensitivity. Accuracy. Kelvin bridge. Measurement of D.C. resistance. Industrial methods. Measurement of potential difference: opposition method. Calibration of a standard instrument: potentiometer method. Moving coil galvanometers. Steady and ballistic conditions. Industrial A.C. measurements: Joubert's and the three-voltmeter methods. Single-phase induction meters. Fluxmeter. Hysteresis loop: Rowland's method. Measurement of iron and copper losses: Epstein-Armagnat method. Strain gauges. Plotting of the impedance curve of a telephone or a loudspeaker. Sound intensity. Analysis of complex sounds, measurement of noise. Directivity of a microphone and of a loudspeaker, time of reverberation.

Tests on Machines

Determinations of the characteristics of D.C. generators: with separate, series, shunt, and compound excitation; determination of the characteristics of D.C. motors under the foregoing excitation conditions. Measurement of efficiency by the method of separation of losses, and by Rayleigh's method. Single- and three-phase transformers: normal tests. Single- and three-phase alternators and synchronous motors: normal tests. Three-phase rotary converters: tests on load, no-load, and short circuit. Repulsion and repulsion-induction motors. Selsyn transmissions: angle transmitter, "electric shaft". Regulation of a Ward-Leonard set: by amplidyne, by rototrol. Regulation of the voltage of a dynamo by vacuum tubes. Alternator voltage regulation by thyratron. Speed control: mototrol. Study of an ignitron.

Servo-mechanisms

Measurements on servo-mechanisms. Control of position: stability, response under sinusoidal and transient conditions. Control of speed: stability, response under sinusoidal and transient conditions.

EQUIPMENT (for 140 students divided into two groups)

Electrical Measurements

The equipment is that indicated in the section on electrical measurements of the division of electricity; the students of the division of radio-electricity and electronics use the same laboratories and equipment.

Tests on Machines

The equipment is that indicated in the section on "Electrical Machines" for the division of electricity.

Servo-mechanisms

The equipment is that indicated in the section on "Electrical Machines" of the division of electricity.

WORKSHOP EQUIPMENT

Quantity	Item and characteristics	Total cost in dollars
	ELECTRICAL MEASUREMENTS	
	Machine Tools	
2	Workbenches, 4 × 1 × 0.9 m	
1	Marking-out table	220
1	Lathe, 120 mm height of centre, 600 mm between centres, with 1 complete set of tools and various accessories	1,540
1	Miller, automatic, with capacity for mandrel, Morse no. 2 cone, special cooling fluid device, with: 2 chucks for millers, 1 concentric chuck, 1 set of keys, 1 set of millers	2,200
1	Drilling machine, large, cone of Morse no. 3 taper, with: 1 set of drills complete, and various accessories, (trepanner, etc.)	950
1	Drilling machine, workbench size, chuck capacity 10 mm with 1 complete set of drills (screw-cutting attachment, filing attachment, various millers)	284
1	Drilling machine, workbench size, 10 mm with accessories	110
1	Nibbling machine, capacity 3 mm, with various accessories, special equipment for cutting out discs with and without centre	554
1	Folding machine, 1.2-3 mm, with accessories	840
1	Pipe-bending machine, capacity 80 × 12 mm	100
1	Bending press, for iron plates or tubes	92
1	Polisher, 300 mm	130
1	Grinding wheel, ordinary, 1.3 H.P. motor	80
1	Polishing wheel, with brushes of various diameters	112
2	Coil winders, electronically controlled, for lap-winding of coils, capacity 3/100-2 mm	1,030
1	Machine for sharpening drills	80
1	Engraving machine, with accessories	540
1	Circular saw, electric, for wood, brass, bakelite, with three 200 mm blades	150
	Total	9,032
	Tools and Instruments for Mechanical Measurements	
1	Hand shears, electric	100
1	Drill, electric, hand	25
1	Saw, electric, hand, 40 mm for wood, 3 mm for metal	84
1	Set of files	90
1	Set of taps	64
1	Set of punches, for leather	27
1	Set of punches, for metal, 15-60 mm	90
2	Punch holders, with accessories	34
1	Screwdriver, electric	60
1	Set of screwdrivers, various	74
1	Marking-out tool, precision	77
3	Pairs of sliding calipers, precision	55
1	Balance, 10 kg, with weights	28
1	Balance, precision	106
3	Sets of spanners; flat double-ended, bent tubular, and socket wrenches	120
1	Set of miscellaneous accessories: masons' levels, letter punches, squares, scribers, small rules, micrometer gauges	140
	Total	1,174

N.B. This equipment, intended for repairs and maintenance, also serves for the construction of instructional models.

Quantity	Item and characteristics	Total cost in dollars
	Stock of Raw Materials and Spare Parts	
	Pieces of sheet metal, angle iron, U, T, and I iron, etc.	
	Screws, bolts, etc.	
	Various cables and conductors, etc.	
	Shells, bars, collars, plugs, etc.	
	Small components: capacitors, coils, resistances, etc.	
	Various replacement valves and tubes Total	6,500
	ELECTRICAL MACHINES	
	Tools	
2	Workbenches, 4 × 1 × 0.90 m, equipped	220
1	Marking-out table	
2	Lathe, 800 mm between centres	840
1	Drilling machine, precision, capacity 10 mm	225
1	Drilling machine, precision, capacity 16 mm	275
1	Spot welder, 25 kVA	550
1	Arc welder, 3.5 kVA	200
1	Multiple punching machine, lever-operated	150
1	Shears, electric, lever-operated	90
1	Saw, circular, electric, for wood, brass, bakelite, with 3-200 mm blades	150
1	Grinding wheel, electric drive, comprising: 1 sharpening stone, diameter 150 mm, 1 finishing stone, diameter 150 mm	80
1	Shears, electric, hand	100
1	Electric polishing wheel, with brushes and plate of diameter 250 mm	100
1	Saw, electric, hand, capacity 40 mm for wood, 3 mm for metal	84
1	Grinding wheel, portable, for finishing	60
1	Polisher, electric, hand, with felt and sheepskin discs	60
1	Drill, electric, hand	25
1	Set of forged socket wrenches, vanadium, 10-32 mm	175
1	Set of flat double-ended spanners, 10-32 mm	120
2	Sets of flat double-ended spanners, 5-12 mm	25
2	Sets of spanners, for tube and pipe work, 5-10 mm	25
3	Sets of drills, 1-20 mm	180
3	Sets of files	90
	Total	3,824
	Stock of Raw Materials and Spare Parts	
	Pieces of sheet metal, angle-iron, U-, T-, and I-iron	
	Screws, bolts, etc.	
	Cables and conductors, various, etc.	
	Replacement valves and tubes Total	4,000
	COIL WINDING	
16	Assembling tables, 6 m long, each with 5 large vices	3,520
32	Carpenters' benches	1,540
32	Lathes, normal type, laid out in 4 rows of 8 in each, each row driven from a single overhead shaft turning at 350 r.p.m. driven by a 3 H.P. motor	11,420
1	Lathe, Ernault	4,150
1	Lathe, Herbert	9,600
1	Lathe, Huré	4,150
1	Lathe, Pax	1,825
1	Miller, Huré	6,250
1	Drill, Jost	310
	Carried forward	42,765

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	42,765
1	Drill, precision	225
1	Straightening machine	1,725
1	Bending press	175
6	Punching machines	525
2	Bandsaws, 1 for wood and 1 for metal	1,450
1	Planer (rough)	425
1	Planer	550
1	Moulding machine	425
1	Grinding wheel	175
1	Shaper	285
	Total	48,725

N.B. This workshop serves for initiating students in the use of machine tools. It is also used for the general maintenance of the equipment of the college and also carries a considerable stock of various raw materials and spares, accessory parts, etc., and also a complete equipment for interior maintenance (0.60 m track, trucks, mobile crane, etc.) and for forge work (forges with swinging hoods, and mechanical fans, anvils, electric furnace for heat treatment and quenching, etc.).

RADIO-ELECTRICAL MEASUREMENTS

Equipment of the Mechanical Workshop

2	Workbenches, standard type	240
1	Large workbench, 12 × 1 × 0.90 m	200
2	Small workbenches, 2 × 1 × 0.90 m	150
1	Lathe, fully equipped	1,500
1	Miller, small	1,000
1	Lathe, milling, fully equipped	2,000
2	Drills	600
3	Vices	210
1	Guillotine	120
1	Bending press	700
1	Saw, electric, fully equipped	80
1	Grinding wheel	80
2	Buffing wheels	80
3	Drills, electric, portable	240
1	Coil winding machine, for lap-winding	500
1	Coil winding machine, for wave-pattern winding	700
1	Engraving machine	1,500
1	Sharpening machine	1,500
1	Polisher	200
1	Set of workshop hand tools	2,000
	Total	13,600

Equipment in the Workshop for Construction and Wiring up

4	Workbenches, standard type	480
1	Workbench, equipped with a vice, a drilling machine, and a riveter	480
3	Distribution boards for power, special laboratory type	900
2	L.F. oscillators, beat frequency, 0-20,000 c/s	1,000
2	H.F. oscillators, 50 kc/s-50 Mc/s	1,400
3	Cathode ray oscillographs, standard type, 9 cm tube	1,200
3	Voltmeters, electronic, 50 c/s-50 Mc/s	1,050
3	Voltmeters, L.F. amplifier	750
	Carried forward	7,260

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	7,260
12	Multimeters, standard type	600
2	Microammeters	100
1	Q-meter	1,000
1	Impedance bridge, universal, L.F.	300
1	Wheatstone bridge, D.C.	100
1	Capacimeter	200
1	Megohmmeter, electronic	200
1	Megohmmeter, magneto	100
1	Amplifier, instrument	250
1	Frequency meter, heterodyne type, 50 kc/s-50 Mc/s	400
1	Frequency meter, resonance and absorption, 1 Mc/s-200 Mc/s	200
3	Auto-transformers, 0-150 V, 10 A	120
3	Sets of workshop hand tools	750
	Total	11,580

Stock of Raw Materials and Spare Parts

	Sheets of brass, aluminium, etc.	
	Screws, nuts and bolts, etc.	
	Various insulators: paper and cardboard, bakelite, steatite, etc.	
	Wires and connecting lugs, aerials, etc.	
	Small circuit components: resistors, capacitors, coils, etc.	
	Various valves and tubes, quartz, etc.	
	Total	10,800

The school also contains four other workshops:

1	Workshop for painting	960
1	Workshop for electroplating	800
1	Photographic laboratory	1,400
1	Drawing office	1,400
	Total	4,560

TOOLS AND EQUIPMENT USED BY THE DEMONSTRATORS

Quantity	Item and characteristics	Total cost in dollars
	Electrical Measurements	
	General Installation	
8	Workbenches of the special model used for the power lines laboratory, but better equipped: the galvanometer mounted on the control panel is provided with a change-over switch allowing it to be used as a calibrated apparatus of class 1.5	3,540 (items 8 and 2 together)
2	Faraday cages for 2 of the tables	
	Total	3,540

N.B. The whole electrical installation in this laboratory is wired with cable having a plaited steel wire sheath to prevent 50 c/s induction in measuring circuits as this is a particular nuisance for null methods. The walls are covered with cork to deaden sound.

Quantity	Item and characteristics	Total cost in dollars
Equipment		
1	Ammeter, moving coil, class 0.1	343
1	Balance, 10 kg, with weights	28
1	Balance, precision	106
2	Capacitance boxes, mica capacitor, accurate to 0.05%	685
1	Control box, electrodynamic, class 0.1	914
1	Resistance box, high accuracy, error 0.005%	1,030
1	Capacitor, standard mica, 0.001 μF, error 0.001%	43
1	Capacitor, standard mica, 0.01 μF to 0.01%	47
1	Capacitor, standard mica, 0.1 μF to 0.01%	64
2	Luminous intensity standards	24
1	Inductance, standard, 100 μH to 0.01%	52
1	Inductometer, accurate to 0.01%	320
1	Milliammeter, moving magnet, accurate to 0.1%	245
1	Cathode ray oscillograph	400
4	Cells, Weston cadmium standard, high stability	96
2	Resistances, standard, 10 Ω to 0.01%	87
2	Resistances, standard, 1 Ω to 0.01%	87
2	Resistances, standard, 0.1 Ω to 0.01%	87
2	Resistances, standard, 0.01 Ω to 0.01%	87
1	Potentiometer, high accuracy (0.01% error), with accessories	520
1	Transformer, current, stability of class 0.01, calibration error 0.05%	246
1	Transformer, current, portable, 0.1%	171
1	Transformer, voltage, class 0.1	177
1	Assortment of shunts, error 0.1%	192
1	Assortment of shunts, for A.C.	167
1	Shunt for A.C., 150 W, 0.01%	134
1	Voltmeter, dynamometer, class 0.1	485
1	Wattmeter, dynamometer, class 0.1	1,000
1	Bridge for checking resistance boxes, error 0.01%	254
1	Frequency measuring equipment, comprising 1 master quartz oscillator, 1 divider and 1 frequency multiplier, 1 oscillograph, accurate to 10^{-5}	2,750
1	Microscope, laboratory	915
	Total	11,756

ELECTRICAL MACHINES

Quantity	Item and characteristics	Total cost in dollars
3	Workbenches, equipped for D.C. 0-210 V, 100 A, and for A.C. at 0-500 V, 50 A	360
1	Instrument box, D.C., class 0.2, containing 1 moving coil voltmeter, ranges 15-75-150-300 V and 1 ammeter, moving coil, with shunts 1-2-5-10-50-100-300-1,000 A	600
1	Instrument box, A.C., class 0.2, containing 1 dynamometer voltmeter, ranges 75-150 V, 1 ammeter, dynamometer, reading to 5 A, 1 electrodynamic wattmeter, ranges 75-150 V, 5 A, 1 current transformer, primary 10-20-50-100-200-300-600 A, secondary 5 A	1,000
1	Tacheometer, standard	60
1	Oscilloscope, L.F., with cathode ray tubes, 227 mm	600
1	Oscilloscope, L.F., with cathode ray tubes, 127 mm	300
1	Oscilloscope, H.F., with cathode ray tubes, 90 mm	360
1	Electronic switch	250
1	Power distribution board, giving: anode volts stabilized by valves, variable, 0-350 V, 120 A; 2 sources of grid bias volts, separate, variable from 0 to 100 V; 2 sources of filament volts, 2 × 3.15 V, 5 A, 50 c/s	270
	Carried forward	3,800

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	3,800
1	Valve voltmeter	200
2	Phasemeters, electronic	600
1	Checking panel, D.C. and A.C., 0-300 V, 0-100 A	400
	Total	5,000

RADIO-FREQUENCY MEASUREMENTS

6	Workbenches, standard type	720
2	Faraday cages	600
3	Distribution boards, special type, containing: 1 source of H.T., 0-500 V; 1 stabilized H.T. source, 0-300 V; 1 stabilized source of grid bias volts, 0-100 V; 1 source of filament volts	900
1	Oscillator, beat frequency, L.F., 0-20,000 c/s, 0.75-3 W	540
1	Oscillator, L.F., type RC, 10-100,000 c/s, 0.1 W	600
1	Oscillator, H.F., calibrated, 50 kc/s-50 Mc/s	800
2	Oscillographs, cathode ray, tubes 13 cm, wide band pass	1,800
3	Voltmeters, electronic, H.F. standard, 50 c/s-100 Mc/s, 0.5-150 V	1,050
3	Voltmeters, L.F. amplifying, 50-10,000 c/s, 1-300 V	750
10	Multimeters, standard	500
2	Microammeters, moving coil	110
1	Q-meter, precision	2,660
1	Wheatstone bridge, D.C.	100
1	Impedance bridge, H.F., 0.5-60 Mc/s	475
1	Impedance bridge, double T, 0.5-30 Mc/s	520
1	Amplifier, instrument	250
2	Frequency meters, heterodyne 50 kc/s-50 Mc/s	800
1	Valve voltmeter	200
1	Capacitor, standard, 100 pF	250
1	Capacitance box, decade 1.11 μF + 1,000 pF, variable	170
4	Resistance boxes, decade	400
1	Communication receiver	350
1	Receiver, experimental television, 441 lines	400
1	Receiver, experimental television, 819 lines	500
3	Sets of small hand tools (soldering irons, pliers, etc.)	300
	Total	15,745

PROJECTED IMPROVEMENTS

The board of management of the college envisages the following improvements, which do not involve any change in the length of studies, nor of the method of recruiting the students or professors:

1. To double the number of principal members of the teaching staff, by assistants or associates, more especially concerned with tutorial work, and with ensuring that the project work is corrected, and to participate in the adjudication after its execution. These projects are at present:

   For the division of electricity, one project concerning hydraulic installations, one concerning thermal stations, one concerning transformers, one design of a D.C. rotary machine, one of an A.C. rotary machine, and one design for electrical equipment.

   For the division of radio-electricity and electronics, one design of a transmitter, one of a receiver, one of an aerial, one concerned with radio direction-finding, radionavigation or radar, and one concerning servo-mechanisms and remote control.
2. To create a "workshop practice" section, to give the students general ideas about working of wood and metals, in the fields specially of interest for electricity and radio. To enable the students to acquire, in the relatively short time of a dozen sessions at the beginning of each year, a grasp of work involving the use of the vice, chisel, file and lathe, of drilling and tapping, soldering, etc., the syllabus will include a preliminary study, by each student, of a definite simple piece of apparatus (electromagnet, vibrator, relay, wireless receiving set, etc.) and the production in the workshop of the corresponding model, on which the student will be able, in the laboratories, to make measurements and to study the performance of the apparatus thus produced.
3. To equip three small new rooms with two to four tables at the most, reserved for special tests which cannot be performed in the large laboratories (e.g. for the division of radio-electricity and electronics: study of fields with the aid of electrolytic tank and networks, study of servo-mechanisms, various tests for studying the industrial applications of electronics, electron microscope, H.F. heating, electronic calculating machines, etc.).
4. To instal three new rooms for the division of radio-electricity and electronics, for experiments on heavy and bulky materials: one transmitter room, one radar room and one room for high accuracy measurement of frequency. The transmitter room will contain four transmitters having powers between 500 and 1,000 W, operating on artificial aerials, one for medium waves, the others for shorter waves with frequency doublers and treblers and various methods of modulation (one to be frequency modulated) and one set of 100 W power, single sideband. The radar room is to contain one radar set with old type aerial, 1.5 m wavelength, one navigational radar with P.P.I. (Plan Position Indicator) operating on 3 cm, and one missile radar, operating on 10 cm waves, and equipped with an arrangement for homing on the target. The room for frequency measurement will contain a frequency standard, with apparatus for the continuous recording of the frequency deviation. Finally, a place should be reserved for operations concerned with nuclear physics.
5. To create a "section for advanced study" for about fifteen engineers, who have already taken their diploma at the college, and show a real aptitude for research. Guided by a research director (maître de recherches), these engineers should study, for twelve months, special problems whose solution is required by industry (relative to light or heavy currents). These studies, financially supported by manufacturers, and carried out in their laboratories, should result in theses discussed in front of a panel of adjudicators and which, if deemed satisfactory, should enable their authors to obtain a special diploma. The holders of these diplomas should then be particularly well suited for entering laboratories and research establishments, where they should be entrusted with research on scientific and industrial problems. Certain

of them might even be authorized to pursue their work for longer than twelve months, with a view, for example, to preparing a doctor's thesis.

6. To organize a certain number of special sections for allowing certain students, already holding the college diploma, to deepen their knowledge of a definite field of technology in three or four months, by a programme of afternoon lectures and morning practical sessions (in alternation with the two divisions, which will not require any new building, but merely the purchase of some supplementary apparatus). The sections whose creation is envisaged are:

An illumination section, to give engineers extended knowledge on all problems of interior and exterior lighting; this section has in fact existed in the past (1925-33) and its operation was only discontinued in order to allow other services to extend when the duration of studies at the school was lengthened from one to two years.

A thermal section, for engineers interested in thermodynamics, thermal stations, boilers, and heating problems, etc.

An electronics section, mainly for engineers with a diploma from the electricity division, desirous of obtaining in the field of industrial electronics, knowledge analogous to that acquired in the same field by students of the radio-electricity and electronics division.

A section of V.H.F. and television, whose creation is required because of the increasing complexity of the field, especially of television, where the advent of colour and stereoscopic presentation is likely to make new demands on qualified engineers.

A nuclear engineering section, reserved more especially for engineers who have gained their diploma in the radio-electricity and electronics division, to get a supplementary training in physics, chemistry, atomistics, atomic energy and nuclear physics, which will enable them to take positions with the Commissariat à l'Energie Atomique (Atomic Energy Commissariat), and the industries associated therewith.

A patents section, for enabling an (obviously restricted) number of engineers to specialize in the study of the technical, administrative, and legal aspects of the preparation and granting of patents, both in France and abroad.

SECOND PART

HIGHER TEACHING OF ELECTRICITY IN SWEDEN

(at the Kungliga Tekniska Högskolan, Stockholm)

GENERAL ORGANIZATION OF THE INSTITUTE

Object and Character of the Teaching

The object of the institute is to give students a grounding in the fundamentals, both theoretical and practical, which will enable them to specialize without difficulty when they later enter industry or administration. It is to be noted that relatively little time is devoted to the humanities and general culture; it is assumed that the students have already acquired a thorough grounding in these disciplines at their secondary schools. The teaching syllabus has a certain flexibility. Thus for awarding diplomas, less attention is paid to the number of hours of lectures attended, and to the practical work carried out by the students, than to the results which they obtain in the various examinations they have to pass.

Divisions

This institute, which is one of the two senior polytechnic institutes in Sweden, is divided into nine departments: applied physics, applied mechanics, naval and aeronautical construction, electricity, roads and bridges, chemistry, mining and metallurgy, architecture, and surveying. Each of these departments contains a certain number of divisions.

Type of School

The institute is a non-residential establishment for full-time study. The diplomas awarded at the end of the period of study are those of Diploma-Engineer: Civil Engineer for most of the departments, Mining Engineer, Architect, and Surveyor, for the last three. They are obtained as a result of written and oral examinations held three times a year (22 September-1 October, 26 January-8 February, 9-21 June), and in some cases, at other times during the year.

Teaching Staff

This consists of:

1. Professors, appointed by the King and attached exclusively to the institute. Each is the head of a division, and as such responsible for the teaching and research in this division.
2. Readers, who devote only part of their time to the institute, where they lecture and are in charge of a division, without having the title of professors.
3. Associate professors, who give lectures on part of the teaching programme of a particular division.
4. Instructors, who are full-time engineers at the institute, generally for supervising the practical work in the laboratories.
5. Assistants, engineers working in industry or administration, who devote a part of their time to the institute, for conducting exercises or dealing with practical work.
6. "Docents", scientists attached to the institute for carrying on scientific research.

Conditions of Admission

There is no entry examination specific to the institute. The candidates for entry must have passed the "students examination" of a secondary school or technical school.

Attainment of a definite stage is not compulsory, but is practically indispensable, since it gives supplementary points to those who achieve it. Admission depends on the marks obtained in examinations, the duration of the stage and that of military service. In certain cases, candidates are subjected to psychological tests. The average age of those admitted is 21-22. They are recruited in the manner indicated above; in addition, a certain number are recruited in the same manner, but only follow a certain number of courses and obtain, at the end of their period of study, a certificate relating to these courses; also admitted are a number of "free auditors", for whom the conditions of entry are less severe, but who do not obtain any certificates.

Duration of Studies

The studies which lead to an engineering diploma generally last four years, each school year divided into two semesters running from 1 October to 25 January and from 9 February to 8 June. During these studies, the students are expected to spend some time in industry. The total duration of these periods in industry should be at least six months, and three of them must have been completed before the beginning of the third year. The students who so desire can follow their studies and prepare for a degree, and then for a doctorate. To obtain these diplomas, it is essential to present a thesis. The doctorate thesis has to be defended in public.

TEACHING PROGRAMME
(DEPARTMENT OF ELECTRICITY)

Theory

This is given as lectures. During the first year and a part of the second, the students of the department of electricity follow courses which are common with those in the departments of applied mechanics and physics, and naval and aeronautical construction. This teaching in common is devoted to the basic sciences, i.e. mathematics, mechanics, and physics. *After this they follow the courses which are specific to their department.* These are distributed among eight groups which form distinct divisions: electrical theory, electrophysics, electrical machines, electrical installations, telegraphy and telephony, radio-electricity, electrical measurements, hydraulic and heat engines. Unlike other schools, the students are not divided into two distinct groups, one devoted to the study of heavy currents, and the other to telecommunications. It is considered desirable that the students should have knowledge of the whole field of electrical technology, and that specialization should not begin until they leave and go into industry or administration. Each division comprises general and special courses. The students are expected to follow the general courses, while they have free choice of at least three special courses. For this purpose they can consult stencilled copies of the contents of the lectures, which, drawn up by the professors themselves, are distributed by the Student's Union. This practice dispenses with any need for note-taking, and students can devote all their attention to the oral exposition, and thus pay special attention to the most difficult parts of the syllabus.

This teaching is supplemented by discussions, involving expositions by the students, and by exercises supervised, in general, by the assistants. These exercises are considered very important. There are compulsory projects involving calculations for and design and construction of machines; these enable the students both to apply their theoretical knowledge to these practical cases, and to familiarize themselves with industrial manufacture. However, the time devoted to these projects is relatively small. The syllabus also involves visits to electrical factories and installations, under the direction of the professors. In addition, study journeys in Sweden and abroad are organized, during the spring semester.

In the final examinations students must present the results of pieces of work done on their own. This compels them, during the last two semesters of their studies, to apply the knowledge they have gained at the institute to an industrial problem. This work, carried out under the control of the professors, consists in going in detail into definite problems both theoretically and experimentally. These tasks can be done *both inside and outside the institute, which enables the students to draw on more* complete material, as well as the advice of experienced technical men.

Practical Work

This comprises practical laboratory work on all parts of the syllabus (both measurements and machine tests). Considerable importance is attached to this part of the syllabus.

Once they have understood perfectly the theoretical bases of the experiments they are to carry out, the students, in groups of two, three or four are only permitted to start the work after the instructors (demonstrators) have approved their plan of work and the list of material deemed necessary for executing it.

Examinations

These consist of written and oral tests. The first include, in general, questions dealing directly with the course work, and numerical calculations. The oral examinations are generally held during the three periods mentioned above. However, if it is deemed desirable, they can in certain cases take place during the study semesters. It should be noted that they are not grouped at the end of the year as in some schools. The students cannot be admitted to the third year of study unless they have passed all the examinations of the two first years, and have gained sufficient credits.

TABLE 2. Timetable for lectures and practical work in the department of electricity of the Kungliga Tekniska Högskolan, Stockholm.[1]

Subject		Hours per semester							
		1	2	3	4	5	6	7	8
Pure mathematics	L	42	56	28	(28)	–	–	–	–
	C	84	98	28	–	–	–	–	–
Applied mathematics I	L	28	–	–	–	14	(56)	–	–
	C	42	–	–	–	14	(56)	–	–
Applied mathematics II	L	28	14	–	–	–	(28)	(56)	–
	C	42	21	–	–	–	(28)	(28)	–
Descriptive geometry	L	14	–	–	–	–	–	–	–
	C	21	–	–	–	–	–	–	–
General mechanics	L	28	28	56	–	–	–	–	–
	C	42	49	70	–	–	–	–	–
General physics	L	42	42	28	–	–	–	–	–
	P	–	42	–	–	–	–	–	–
Applied physics	L	–	–	–	–	–	–	–	(21)
	P	–	–	–	–	–	–	(21)	–
Strength of materials	L	–	56	(42)	(14)	–	–	–	–
	C	–	49	(28)	(42)	–	–	–	–
	P	–	4	–	(4)	–	–	–	–
Elements of machine design	L	–	–	28	28	–	–	–	–
	Pr	–	–	28	28	–	–	–	–
Engineering drawing	L	7	14	–	–	–	–	–	–
	Pr	–	56	–	–	–	–	–	–
General chemistry	L	–	(28)	–	–	–	–	–	–
Electrical theory	L	–	–	56	28	14	/56/	–	–
	C	–	–	56	56	–	–	–	–
Electrophysics	L	–	35	–	–	–	–	/56/	(28)
	P	–	14	–	–	–	–	/28/	–
Electrical measurements	L	–	–	–	56	35	–	/42/	–
	P	–	–	–	–	42	56	/16/	21
Electrical engineering materials	L	–	–	–	21	28	21	–	–
Electrical machines	L	–	–	–	21	14/56/	/21/	–	–
	C	–	–	–	14	14/28/	/28/	–	–
	Pr	–	–	–	–	/21/	14/28/	–	/21/
	P	–	–	–	–	–	18	/42/	–
Electrical installations	L	–	–	–	–	–	11/28/	48/84/	–
	C	–	–	–	–	–	9/21/	22/42/	–
	Pr	–	–	–	–	–	–	20/42/	36/70/
	P	–	–	–	–	–	–	/15/	–
Telegraphy and telephony	L	–	–	–	–	42	21/21/	/28/	–
	C	–	–	–	–	28	14	–	–
	Pr	–	–	–	–	–	/14/	/42/	/42/
	P	–	–	–	–	–	–	14/28/	–

[1] Abbreviations used: L = lecture; C = calculation exercises; Pr = project; P = practical laboratory work; 28 = compulsory course; /28/ = special course; (28) = optional course.

Subject		Hours per semester							
		1	2	3	4	5	6	7	8
Radio-electricity	L	–	–	–	–	35	28/21/	/35/	–
	C	–	–	–	–	28	28	–	–
	Pr	–	–	–	–	–	/14/	/28/	/42/
	P	–	–	–	–	–	–	12/18/	–
V.H.F. techniques	L	–	–	–	–	–	–	/42/	–
	Pr	–	–	–	–	–	–	–	/28/
	P	–	–	–	–	–	–	–	/15/
Electro-acoustics	L	–	–	–	–	/14/	/14/	–	–
	C	–	–	–	–	–	/28/	–	–
	P	–	–	–	–	–	/6/	–	–
Hydraulics and heat engines	L	–	–	–	–	28	/56/	–	–
	C	–	–	–	–	14	–	–	–
	Pr	–	–	–	–	–	/38/	–	–
	P	–	–	–	–	–	/4/	–	–
Theory of regulators	L	–	–	–	–	–	–	/28/	–
	P	–	–	–	–	–	–	/14/	–
Industrial economics and management	L	–	–	–	–	–	–	70/14/	/14/
	C	–	–	–	–	–	–	14	/14/
Photography	L	/14/	/21/	–	–	–	–	–	–
	P	–	/28/	–	–	–	–	–	–
Industrial hygiene	L	/14/	/14/	–	–	–	–	–	–
Foundry work	L	–	–	–	–	–	/28/	–	–
	P	–	–	–	–	–	/28/	–	–
Welding	L	–	–	–	–	/21/	–	–	–
	P	–	–	–	–	/14/	/14/	–	–
Political economy	L	–	–	35	–	–	–	–	–
Jurisprudence	L	–	21	–	–	–	–	–	–

INVENTORY OF INSTRUCTIONAL MATERIAL AND CONTENTS OF COURSES

CONTENTS OF COURSES COMMON TO ALL DEPARTMENTS

(given only as an example to facilitate the use of the inventories)

Pure Mathematics

Course Content and Exercises

First year:
Differential calculus: derivatives, maxima and minima, mean value theorem with applications, Taylor's theorem with applications, infinite series, discussion of curves, functions of two or more independent variables, their maxima and minima. Theory of equations: approximate calculation of roots, complex quantities, the fundamental theorem of algebra. Integral calculus: definite and indefinite integrals, rules of integration, integration of certain classes of functions, integration of series, derivation of integrals, double integrals, calculation of arc lengths, surfaces, and volumes. Centre of gravity, Fourier series. Differential equations: integration of certain types of differential equations of the first and second order, with applications on geometrical problems, linear differential equations with constant coefficients, Cauchy's differential equation, systems of differential equations.

Second year:
Elementary theory of analytic functions, some special classes of functions, as the gamma function and the Besselian functions.

Applied Mathematics I

Course Content and Exercises

First year:
Numerical methods. Fundamentals of nomography, slide rules, planimeters. Survey of calculators and their application. Interpolation and quadrature.

Applied Mathematics II

Course Content and Exercises

First year:
Vector algebra: elementary vector operations; matrices, determinants; linear systems of equations and transformations to principal axes; straight line, plane, quadric surfaces. Vector analysis: variable vectors; vector fields; potential, gradient, divergence, curl; theorems of Gauss and Stokes; tensors; curvature of surfaces.

Descriptive Geometry

Course Content and Exercises

First year:
Point, straight line, and plane. Polyeders, curved lines, curved surfaces. Intersection, expansion, and superposition. Axonometry.

General Mechanics

Course Content and Exercises

First year:
Statics: systems of forces and their reduction. Centre of gravity. Equilibrium of rigid bodies. Laws of fluid pressure. Flexible chains. Dynamics: dynamics of a mass point.
Second year:
Dynamics: dynamics of bodies. Laws of linear and angular momenta. Moments of inertia. Plane motion of rigid bodies. Lagrange's equations. Impact. Technical applications.

General Physics

Course Content

First year:
Heat, optics, atomic physics, measurements in physics.
Second year:
Atomic physics, physics of materials.

Practical Work

Numerous practical tasks are set in connexion with this course. Moreover, 21 lectures and 21 practical tasks, all optional, are organized during the seventh semester in the course of applied physics (see Table 2), together with 28 optional lectures on general chemistry during the second semester.

Strength of Materials

Course Content, Exercises and Practical Work

First year:
Statics: forces in plane framed structures, funicular polygon, stress diagram, method of sections, shearing force and moment diagram. Study of materials: tensile testing, general state of stress and strain, work of deformation, plasticity, strength under fatigue. Elementary elasticity: bending of beams (deflection, moment of inertia, principle of superposition, non-uniplanar bending); curved beams (stress distribution); torsion (shafts with circular section); helical springs. Elasticity problems with rotational symmetry: thick tubes, shrink fits, centrifugal stresses. Stability: Euler's formulae. Vibrations in engineering: critical speeds of shafts.
Second year:
Elementary elasticity (continuation): shearing stress, general state of stress and strain, work of deformation, stress concentration, fillets and holes, theory of bending (continuation), curved beams, torsion, stability; statically indeterminate structures. Materials from the designer's point of view (continuation): plasticity and rupture, strength under fatigue. Vibrations in engineering (continuation): free and forced vibrations in systems with one and several degrees of freedom, damping, torsional and flexural vibrations, methods of Rayleigh and Ritz; critical speeds of shafts.

Elements of Machine Design

Course Content and Projects

Second year:
Screws; riveted, welded and soldered joints; forced fits and shrinkage fits; tolerances; cast details; springs and elastic mountings; types of mechanisms; shafts, rotors, critical speed, balancing; bearings, ball and roller bearings; friction, belt, V-belt, rope, chain, and gear drives; clutches, brakes, ratchets; variable-speed transmissions; containers, pressure vessels, piping, valves, packing.

OTHER COURSES

Pupils also follow a compulsory course on engineering drawing, with projects, a special course on photography, with practical work, a special course on industrial hygiene and compulsory courses on political economy and jurisprudence.

CONTENTS OF COURSES OF THE DEPARTMENT OF ELECTRICITY PROPER, AND INVENTORY OF INSTRUCTIONAL EQUIPMENT

DIVISION OF ELECTRICAL THEORY

COURSE CONTENT

General Course : Electricity and Magnetism

Second year:

Electrostatics. Nature of electricity. Concepts and fundamental laws of electrostatics. Electrical doublet or dipole, properties of a dielectric considered as a dipole space. Practical problems in electrostatics. Electrostatic energy and electrical force. Electrostatic systems comprising any number of conductors. Properties of dielectrics.

D.C. Ohm's and Joule's laws. Non-linear resistances. Continuity equation. Derived current. Circuits, cells, thermocouples, electrolysis.

Static electromagnetism. Some concepts and fundamental laws of electromagnetism. Magnetic moment. Properties of matter considered as a space containing a magnetic dipole. Scalar magnetic potentials. Calculation of magnetic field strengths (or magnetic forces). Theory of magnets. Magnetic properties of iron. Mechanical effects of magnetism.

Electromagnetic induction. Law of induction. Self-induction and mutual induction where the conductors can be considered as linear. Magnetic energy and force. Inductances with conductors of finite cross-section. Some calculations of inductances.

A.C. Instantaneous values of sinusoidal A.C. Graphical representation of the characteristic quantities in A.C. Method using complex quantities. Power of alternating currents. Transmission and distribution networks. Non-sinusoidal A.C. Iron-cored circuits traversed by A.C. Loss angles. Co-ordination of insulation. Three-phase systems with symmetrical load. Asymmetric three-phase systems.

Third year:

Theory of electromagnetic fields. Quasi-stationary fields. Maxwell equations. Radiation.

Special Course : Electricity and Magnetism[1]

Third year:

Advanced course on the theory of electromagnetic fields. Electromagnetic waves and the propagation of waves along parallel conductors. Wave guides, aerials and resonators.

Operational calculus. Applications to transient conditions in circuits and simple networks, composed of lumped elements. Step function. Laplace transformation. Transients on lines.

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[1] Calculation exercises are associated with this course.

Experiments Made during the Lectures: Programme and Equipment Necessary

The following experiments are given, as demonstrations, during the lectures on electrical theory. After the description of each experiment, the equipment necessary for carrying it out is listed. The quantities apply to a class of about 70.

Quantity	Item and characteristics	Total cost in dollars

Electrostatics and D.C.

(a) Conductivity of a glass rod at high temperature

The limiting resistance, the ammeter and the glass rod are connected in series with a source of current. When the glass rod is gas-heated, currents of up to 15 A can be passed. When current flow is established, the gas heating is stopped. The heat produced by the current is sufficient to melt the glass.

1	Glass rod, 10 cm diam.	—
1	Resistance, 10 Ω	25
1	Ammeter, moving iron, 0-20 A	15
1	Gas burner	5
1	Source of A.C., 220 V, 50 c/s	—
1	Tube holder, made in the institute, with terminals for the glass tube	20
	Total	65

(b) Demonstration of the increase of strength of electric field at points and corners, and on curved surfaces

The air between the electrodes is ionized beforehand with ultra-violet radiation provided by the ozone discharge tube. On opening and closing the primary circuit rapidly, fairly high secondary potentials are obtained. For this purpose, a mercury interruptor is made use of. The form of the surfaces of the electrodes decides the maximum distance for which a disruptive discharge can be produced.

1	Induction coil	255
—	Aluminium electrodes of different curvatures, made in the division	15
1	Accumulator, lead, 2.1 V	15
1	Mercury interruptor	5
1	Ozone discharge tube	35
	Total	325

(c) Attraction exerted on a thin sheet of dielectric between the plates of a capacitor

The capacitor is charged by an electrostatic induction machine. Then the position of the glass diaphragm between the plates of the capacitor is so adjusted as to balance the forces acting thereon, i.e., on the one hand the forces originating from the electrostatic field, and, on the other, the mechanical forces exerted by the suspension. The suspending ligaments should be long, since the force exerted is small. Protection against dust is important.

1	Electrostatic induction machine	65
1	Capacitor made in the division	15
1	Glass diaphragm, capable of easy movement between the capacitor plates, with suspension, made in the division	25
	Total	105

(d) Maxwell stresses

Before charging the metallic sphere, which is suspended by a coil spring, it is immersed, up to the middle, in a glass vessel filled to the brim with oil. The sphere is then charged with the help of an electrostatic induction machine, using the coil spring to conduct the charge to the sphere. The sphere lowers visibly, indicating that ½ $\overline{ED}$ in the oil is greater than in air.

1	Glass vessel	1
1 l	Oil, very thin, high dielectric constant	—
1	Metal sphere	—
1	Coil spring, light, small restoring force	3
1	Electrostatic induction machine	65
	Total	69

Quantity	Item and characteristics	Total cost in dollars

(e) Current-voltage characteristic of a non-linear resistance

The current-voltage characteristic of a clay-carbon resistance is displayed on the screen of an oscillograph, along with a series of curves for linear resistances. The clay-carbon resistance is then replaced by a tetrode, with two resistance lines, having different slopes.

1	Oscillograph	875
1	Electronic switch	375
1	Rectifier, 300 V	200
1	Source of A.C., 90 V, 50 c/s	—
1	Test set-up (comprising thin film resistances, one ceramic-carbon resistance, and one electron tube, coupled up as a tetrode) made in the division	75
	Total	1,525

Electromagnetism

(a) The Barkhausen effect

A permanent magnet is brought up to the soft-iron core. Crackle in the loudspeaker is distinctly heard.

1	Amplifier, made in the division	90
1	Coil, of soft iron, with open core, made in the division	5
1	Permanent magnet, powerful	3
	Total	98

(b) Coupled mechanical oscillations of magnets

The magnets should be capable of supporting their own weight during repulsion. Inclined in convenient positions on a table and supported only along one edge, two magnets execute coupled oscillations under the influence of the repulsion exercised by a third magnet on the table.

3	Permanent magnets, short and powerful, of special alloy	24

(c) Position of the poles of a cylindrical coil and of a permanent magnet

The position of the poles and the configuration of the fields created by the magnet and by the electrical current flowing through the cylindrical coil are displayed. The magnet and the coil have exactly the same form. The poles of the coil are located exactly at its ends, while the poles of the magnet are located a little way from its ends.

1	Magnetized needle, easily moved, acting as an indicator, with a suspension arrangement, made by the division	20
1	Long cylindrical coil, with a simple winding, made in the division	15
1	Long bar magnet, made in the division	7
	Total	42

(d) Hysteresis loop

The variation in form of the loop with the amplitude of the magnetizing current is displayed.

1	Apparatus for demonstrating the hysteresis loop	20
1	Oscillograph	500
	Total	520

(e) Form of the current after closing a circuit and its variation with the load

The form of the transient current produced when a circuit containing a resistance is closed is compared with that obtained when the resistance is replaced by an inductance connected in series with a variable resistance and by a series circuit of variable damping.

1	Oscillograph	1,000
1	Pulsator	500
1	Board carrying the impedance components, made in the division	50
	Total	1,550

Quantity	Item and characteristics	Total cost in dollars

(f) Form of the currents after closing a circuit, and the variation of these currents with the load

The procedure is the same as in (e), but the variation is now so slow that it can be followed by the eye.

1	Electrolytic condenser, 7,000 pF	20
1	Inductance, 100 H	75
1	Galvanometer, low damping, 10-0-10 and 100-0-100 mA	40
1	Dry cell, 2.6 and 10 V across the terminals	1
2	Resistances in series, 100 and 10 Ω	6
	Total	142

(g) Form of the currents in the primary and secondary after a coreless transformer has been connected to a D.C. source

These forms are displayed simultaneously on the screen of an oscillograph. The connexions are altered so that the mutual inductance assumes all values between + M and — M.

1	Variometer	15
1	Pulsator	500
1	Electronic relay	375
1	Oscillograph	1,000
	Total	1,890

Alternating Current

(a) Measurement of the component voltages across a coil

Using a current as a phase reference, the magnitudes of the phase of $Z_p = Ri_p + L_p \frac{di}{dt}p$, of $L_p \frac{di}{dt}p$ and of Ri_p are measured in succession. Z_p is obtained by measuring the potential across the terminals of the primary winding, with the secondary winding open. $L_p \frac{di}{dt}p$ is obtained by measuring the potential across the terminals of the secondary winding on no load. Finally, Ri_p is obtained from the potential across the terminals of the primary and secondary which are connected in series opposing.

1	Transformer with exactly similar primary and secondary windings, with very tight coupling. In this case, a normal inductance is used, for which $L_p = L_s = 0.01$ H	90
1	Electronic switch	375
1	Oscillograph	875
1	Source of A.C., 6 V, 50 c/s, internal resistance as low as possible	25
1	Series resistance for setting the current, 1 Ω at the most	3
	Total	1,368

(b) Obtaining a signal of saw-tooth wave-form, as well as its derivative and integral

The form of these curves is obtained by measuring the currents produced when the e.m.f. is applied to an inductance and a capacitance respectively. These curves are displayed in succession on the oscillograph, simultaneously with the saw-tooth signal.

1	Board carrying a relaxation oscillator, a cathode follower, an inductance and a capacitor, made in the division	55
1	Electronic switch	375
1	Oscillograph	875
1	Converter set, D.C., 360 V	200
	Total	1,505

Quantity	Item and characteristics	Total cost in dollars

(c) Plotting the impedance and reactance diagrams for a resonant circuit with variable damping

These curves are obtained as plots against the frequency on an oscillograph screen, in the neighbourhood of the resonant frequency of the circuit. By varying a series resistance in the circuit, the effect of Q on the curves can be displayed.

1	Board carrying a discriminator circuit, resonant circuits and variable damping resistances, made in the division	75
1	Board carrying two amplifying valves, and one detector valve, made in the division	65
1	Frequency modulator	90
1	Audio-frequency oscillator	500
1	Oscillograph	500
	Total	1,230

Electromagnetic Field

(a) Demonstration of the existence of standing waves in a Lecher circuit

This is effected with a luminescent tube. The displacement of the nodes and loops, when the frequency is changed, is displayed.

1	H.F. oscillator, output 1 W, 500 Mc/s	500
1	Lecher circuit, made in the school	40
1	Luminescent tube	3
	Total	543

(b) Demonstration of the existence of standing waves in a space after reflection of an electromagnetic field at a conducting surface

The nodes and loops are displayed for various frequencies. The wavelength of the electromagnetic wave, and its polarization, are displayed.

1	H.F. oscillator, as used in (a)	500
1	Dipole aerial	5
1	Field strength indicator, dipole type, made in the division	40
	Total	545

(c) Demonstration of the existence of standing current and voltage waves in a dipole aerial of variable length

The existence of these is shown up by varying the aerial length. The incandescent lamp is held in the hand.

1	H.F. oscillator, as used in (a)	500
1	Aerial, dipole, adjustable	5
1	Aerial current indicator, made in the division	150
1	Incandescent lamp, 6 V, 50 mA, as voltage indicator	—
	Total	655

PRACTICAL WORK

The relevant practical work is included in that for the "Electrical Measurements" course (see p. 123).

DIVISION OF ELECTRO-PHYSICS

Course Content

Application of Mathematics to Electro-physics

Applied Mathematics I

Third year:
Numerical methods: numerical integration of differential equations; harmonic analysis. Mathematical statistics: brief survey of the principal statistical problems in engineering; elements of the calculus of probability; advanced course in the calculus of probability; treatment of statistical material, fundamentals of the significance theory; statistical quality control in the industry.

Applied Mathematics II

Third year (optional course):
Mathematical physics: theory of wave motion in continuous media, and of heat conduction and diffusion; treatment of eigenvalue problems by means of the calculus of variations; orthogonal systems of functions; fundamentals of quantum mechanics.
Fourth year (optional course):
Mathematical physics: fundamental theorems of thermodynamics and their most important applications; elementary kinetic gas theory, and statistical thermodynamics; Bose and Fermi statistics; light quanta, heat radiation and thermodynamic equilibrium, structure and spectra of atoms and molecules.

General Course[1]

Second year:
Thermal emission of electrons, secondary emission, photo-electric emission, emission under the influence of a field. Heated cathodes. Motion of electrons and ions in electrical and magnetic fields. Space charge. Diodes. Rectifiers. X-ray tubes. Triodes. Tubes with several electrodes. Secondary emission tubes. Television tubes. Electron microscopy. Photo-electric cells, electron multipliers (counters). Discharge in gases. Glow discharge tubes. Stabilizing valves. Luminescent tubes. Electronic and ionic valves. Arcs in circuit-breakers and switches.

Special Course

Fourth year:
Deeper study of some matters indicated in the second year course. Technical applications of vacuum.

Practical Work

This work is part of the special course for the fourth year. To be able to undertake it, the students must have completed the practical work on electrical measurements. The equipment necessary for performing it, such as is enumerated below, is sufficient for 30-40 students.

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[1] Calculation exercises are attached to this course.

Quantity	Item and characteristics	Total cost in dollars

(a) Measurements using probes

The students determine the characteristics of various probes in a bath of mercury. The values obtained are used for calculating the temperature, the electron density, and the distribution of potential in the bath.

1	Group of high-vacuum pumps, comprising: 1 mercury diffusion pump, water-cooled, 1 single-stage backing pump, apparatus for measuring vacua: McLeod, Pirani, and ionization gauges; 1 set-up for charging with rare gases; 1 thermostatically-controlled electric furnace, max. temperature ± 350° C	3,000
5	Multimeters, volt-ampere	350
2	Resistances, variable, 1 kW	100
2	Resistances, variable, 400 W	30
1	Special instrument tube	125
2	Accumulators, lead, 6 V	40
1	Rectifier, stabilized, 5-100 V, 100 mA	125
	Total	3,770

(b) Determination of ionization and excitation potentials

This is taken from the book *Experimental Atomic Physics*, by Harnwell-Livingood. The purity of the gases and other materials used for it is highly important.

1	Set of vacuum pumps, with various accessories [see (a)]	3,000
1	Special tube	125
2	Accumulators, 6 V	40
1	Accumulator, 4 V	15
2	Ammeters, 2 A	80
3	Multimeters, volt-ampere	210
1	Voltmeter, 0-5 V	40
1	Microammeter, universal, 0-5-500 A	175
2	Resistance, regulating, 100 W	30
2	Potentiometers, 10 kΩ	30
1	Short-circuit switch	5
	Total	3,750

(c) Study of glow discharge tubes

Glow discharge tubes intended for general use are evacuated and degassed using a set of high-vacuum pumps. They are then filled with rare gases. The voltage-current characteristics of the tubes are then determined for various rare gases, varying the pressure. At the same time the excitation and extinction potentials are determined. The Paschen curve for various gases is determined with a tube in which the inter-electrode distance can be varied.

1	Set of high-vacuum pumps, with various accessories [see (a)]	3,000
2	Multimeters, volt-ampere	140
1	Stabilized converter set, D.C., 100-500 V	190
	Various loading resistances	15
1	Apparatus for H.F. heating of electrode systems	1,250
	Total	4,595

(d) Production of a very high vacuum in electron tubes

This series of experiments is intended to demonstrate the difficulties encountered in the technical applications of vacuum. The students become acquainted with a series of high-vacuum pumps, carry out degassing, obtain a hard vacuum in, and seal off, an electron tube intended for general use. In addition, they determine the characteristics of this tube, once sealed off.

1	Set of high-vacuum pumps, with various accessories [see (a)]	3,000
2	Electron tubes, filament indirectly heated, not evacuated	6
1	Transformer, 15 V, with "Variac"	60
	Carried forward	3,066

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	3,066
4	Multimeters, volt-ampere	280
1	Apparatus for indirect heating of electrode systems	1,250
1	D.C. voltmeter, 10 V	50
1	Resistance, regulating, 10 kΩ, 200 W	15
1	Resistance, fixed, 10 kΩ, 5 W	2
1	Resistance, 1 MΩ, 0.35 W	—
1	Battery, grid bias, 0-15 V	3
1	Microammeter, 0-50 A	25
	Total	4,691

(e) Study of luminescent discharge tubes

The students examine tubes of several types, such as mercury vapour tubes, low pressure tubes, high pressure (sodium vapour) tubes and a thyratron controlled by photo-electric cell. They study the excitation of a thyratron and a glow discharge tube, using an oscillograph.

	Demonstration apparatus: various types of luminescent tubes; thyratron controlled by a photo-electric cell	—
	Apparatus on which manipulations are made: high pressure mercury vapour tubes; thyratron; brush discharge tubes	—
	Instrumentation:	
4	Multimeters, volt-ampere	280
1	Oscillograph	500
1	Oscillator, audio-frequency	125
1	Transformer, variable	40
	Various series resistances	5
	Total	950

DIVISION OF ELECTRICAL MACHINES

This comprises two sections, one dealing specifically with electrical machines properly speaking, and the other with the equipment used in electronics, this latter being in the care of an associate professor (see the section on "Teaching Staff", p. 89).

ELECTRICAL MACHINES

Course Content

General Course

Second year:

This is a general introductory course. The lectures deal with the applications of normal machines, i.e. with the synchronous machine, the D.C. machine, and the transformer, the induction machine, rotary converters, A.C., rectifiers and transductors. The course includes the fundamental concepts developed in more detail in the special course indicated below.

Special Course

Third year:

Synchronous machines. The general principles of the production of e.m.f. and torque in an electrical machine with poles, excited by D.C.; the main magnetic circuit and the winding necessary for obtaining the main flux; the magnetic leakage on no-load; the construction of the main windings and the corresponding e.m.f.'s; the armature reaction, its longitudinal and transverse components and

its magnetomotive force of the equivalent inductor; vector diagrams and the operating curves when acting as an alternator and as a motor, in under- and over-excitation; resistance, reactance, and potential drop; the construction of the characteristic curves and the location of the point of operation under load; the short-circuit current; the synchronous reactance and some approximate formulae deduced therefrom; definitions of various reactances; losses; heating and ventilation; general rules for dimensioning; behaviour under normal conditions; starting and accelerating; voltage regulation; practical applications.

The D.C. machine. General features; theory and construction of windings; armature reaction and its components; commutation; the load triangle; characteristic curves, behaviour under normal conditions; practical applications; the principles of starting and regulating resistances.

The transformer. General features; no-load energy and reactive losses; windings and principles of connexion; resistance, reactance, and potential drop; vector diagram on load; tests and critique of the results; cooling; ageing; behaviour under normal conditions; instrument transformers; reactance coils.

The asynchronous machine. General features; the circle diagram and the determination of the characteristic quantities; calculation of the resistance, reactance and excitation current; squirrel cage rotors; starting and regulation; single-phase motors; induction regulators; practical applications.

A.C. rotary converters. Converters: single-phase motor converters; applications to electric traction; three-phase motor converters, particularly the Schrage motor; various cascade systems.

The rectifier. Classification; principles and construction of valves; types of connexion to transformers; smoothing chokes; theory of commutation; inverters; practical applications.

The transductor. Principles of construction and operation; analogy with a current transformer; the transductor used as an amplifier, regulator, current transformer on D.C., and reactance coil; the three-phase transductor with Nordfeldt connexion.

Applications to general problems. Industrial applications; regulation of speed and voltage; synchronous stability and stability under reactive conditions; transient phenomena on closing and on short-circuiting; asymmetric and asynchronous phenomena; spatial and temporal harmonics; circuit breakers; various vector methods in the theory of electrical machines.

Exercises and Projects

The calculation exercises consist in the solution of numerical problems bearing on the various parts of the course.

The project for the general course in the third year consists in the design and construction of a transformer. Those relating to the special course for the third and fourth years consist in the design and construction of a synchronous and a D.C. machine. Students who are particularly interested in this subject can also carry out the calculations necessary for the design and construction of a single-phase motor converter, and can construct it.

Practical Work

The material necessary for the six experiments of the general course is listed for a class of 70. That for the other six relates to a class of 30.

Quantity	Item and characteristics	Total cost in dollars
General Course		
(a) Synchronous machine		
Plotting of curves. Determination of the characteristic quantities.		
2	Synchronous machines	950
2	D.C. machines	825
	Carried forward	1,775

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	1,775
2	Transformers, current	340
2	Ammeters	140
2	Wattmeters	280
1	Voltmeter	150
1	Ammeter, 45 mV, 10 Ω	75
1	Shunt, 45 mV, 1.5-7.5 A	10
2	Regulating apparatus	80
2	Resistances, variable, 400 and 250 Ω	20
1	Frequency meter	55
	Total	2,925

(b) D.C. machine, shunt-wound

Determination of the characteristic quantities, measurement of losses, etc., using two identical machines.

2	D.C. machines	200
1	Ammeter, 45 mV	75
1	Shunt, 45 mV, 15 and 30 A	10
1	Ammeter, 1 Ω	50
1	Shunt, 30 A	10
1	Avometer	90
1	Resistance, variable, 2,500 Ω	10
2	Resistances, variable, 1,000 Ω	20
1	Tachometer	25
	Total	490

(c) Universal motor

The measurements are made with a special torque balance, and speeds are measured stroboscopically.

1	Torque balance	200
1	Transformer, variable	90
1	Wattmeter	130
1	Avometer	90
1	Multimeter	45
1	Stroboscope	185
1	Resistance, variable	10
	Total	750

(d) Three-phase transformer

Test under normal conditions; wave form distortion; influence of temperature, additional losses, etc.

1	Transformer, three-phase, 5 kVA	150
1	Regulator, induction	365
2	Transformers, current	150
2	Ammeters, 5 A	130
2	Wattmeters, 5 A	220
2	Voltmeters	200
2	Resistances (series) for wattmeters	50
1	Multimeter	95
	Total	1,360

(e) Asynchronous machine, elementary test

Standard measurements, using a normal torque balance.

1	Torque balance	375
1	Motor, asynchronous	100
	Carried forward	475

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	475
1	Regulator, induction	990
2	Transformers, current	150
2	Wattmeters	420
2	Ammeters	320
1	Voltmeter	165
1	Millivoltmeter	110
1	Tachometer	60
1	Stroboscope	185
	Total	2,875

(f) Rectifier, elementary test

Measurement on a single-phase rectifier, mercury-vapour, and on an iron-selenium three-phase rectifier.

1	Rectifier, single-phase, mercury-vapour	575
1	Iron-selenium rectifier	40
1	Regulator, induction	490
1	Transformer, three-phase	80
2	Transformers, current	340
2	Wattmeters	420
3	Ammeters	395
2	Voltmeters	225
1	Resistance, loading	75
1	Oscillograph	225
1	Shunt	145
	Total	3,010

Special Course

(a) Ward-Leonard set

Tests under normal and transient conditions.

1 2	Motor, asynchronous Machines, D.C.	250
1	Rectifier, iron-selenium	40
3	Transformers, current	510
2	Wattmeters	490
1	Ammeter, 1.2-6 A	75
1	Ammeter, recording	185
1	Wattmeter, recording	250
1	Ammeter, 1 Ω	50
1	Shunt, 1.5 A	4
1	Multimeter	100
	Total	1,954

(b) Asynchronous machine for hoisting equipment

The special conditions are reproduced by using a D.C. Krämer machine supplying the load for the asynchronous machine.

2 2	D.C. motors Three-phase motors	325
1	Resistance, secondary, three-phase	25
2	Transformers, current	340
2	Ammeters, recording	435
1	Wattmeter, recording	250
1	Voltmeter	110
	Carried forward	1,485

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	1,485
1	Ammeter, 45 mV, 10 Ω	75
1	Shunt, 45 mV	10
5	Resistances, variable	50
	Total	1,620

(c) Oscillations by a synchronous set

The oscillations are produced by a sudden change of load and by altering the resistance of the armature circuit. The conditions of excitation are studied by direct and oscillographic methods.

1	Synchronous machine	315
1	D.C. machine	150
2	Transformers, current	340
2	Wattmeters	420
2	Ammeters	320
1	Voltmeter	165
2	Ammeters, 1 Ω	100
2	Shunts, 1 Ω	20
1	Filter, low-pass	60
1	Oscillograph	450
1	Camera	30
1	Stroboscope	185
3	Resistances, variable, 10 Ω, 15 A	90
2	Resistances, variable, 400 Ω	20
	Total	2,665

(d) Converter

The losses and the potential drops are studied under various conditions of load and power factor.

1 1	Converter Starting transformer	1,250
1	Transformer, current	170
3	Wattmeters	330
3	Resistances, for insertion in series with the wattmeters	75
3	Ammeters, 1.2-5 A	225
1	Voltmeter	165
1	Millivoltmeter, 60 mV	100
1	Shunt, 60 mV	20
1	Ammeter	75
1	Shunt	145
1	Voltmeter, 15-600 V	100
2	Resistances, variable, 300 Ω	20
2	Resistances, loading	20
1	Tachometer	60
	Total	2,755

(e) Schrage motor

The characteristics are obtained for various positions of the brushes, and for variable loads.

1	Motor, Schrage	500
1	Torque balance	1,125
2	Transformers, current	350
2	Wattmeters	420
3	Ammeters	395
1	Voltmeter	165
	Carried forward	2,955

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	2,955
1	Multimeter	100
1	Regulator, induction, 50 kVA	925
1	Tachometer	25
	Total	4,005

(f) Rectifier, more exhaustive test

Measurements are made on a three-phase rectifier, mercury-vapour, with grid control.

1	Rectifier, mercury-vapour	530
1	Regulator, induction, 10 kVA	365
2	Transformers, current	340
2	Wattmeters	180
2	Resistances, to put in series with the wattmeters	50
2	Ammeters	110
2	Voltmeters	245
1	Shunt, 45 mV	10
1	Ammeter, 45 mV, 10 Ω	75
1	Multimeter	90
1	Resistance, loading	75
	Total	2,070

N.B. The personal work which must be done by each student, during the seventh or eighth semester (see p. 91) frequently deals with special points involving electrical machines. In this way studies are effected, either in the laboratory or in industry, relative to the characteristics of various types of apparatus, the stability, automatic regulation, the measurement of reactances, and the achievement of various special connexions, etc.

ELECTRICAL ENGINEERING MATERIALS

Course Content

Second year:
- Chemical and physical fundamentals; testing of materials; non-destructive tests; general survey of industrial materials.
- Iron and steel; production of pig iron, cast iron, soft iron, and steel; special steel; surface treatment; conditions of sale.
- Non-ferrous metals; production of technically important metals and their alloys; strength properties.
- Mineral materials, wood, textiles, paper, leather, rubber, lubricating materials.

Third year:
- Electrical conductors, particularly copper and aluminium.
- Resistance materials; metallic resistance materials for medium and high temperatures; ceramic resistance materials.
- Thermo materials; contact materials; semi-conductors; supra-conductivity; materials for vacuum techniques.
- Magnetic materials, particularly iron for magnetic purposes; materials for permanent magnets; remanence and coercive force.
- Soft magnetic materials; alloy steel for electric machines and transformers, as well as for circuit elements for telecommunication; powder cores.
- Non-magnetic construction steel.
- Insulating materials; general survey.

Solid insulators; glass and porcelain; steatite; mica and micanite products; wood; rubber and hard rubber; paper, presspahn; glass fibre; cotton, silk; compounds; insulating enamels; various types of conductor insulation with regard to electrical, thermal and mechanical properties; theory of breakdown, dielectric constant, and dielectric losses.

Liquid insulators; oils, particularly for transformers, circuit breakers, etc; properties of oil in an electric field; dependence on temperature; ageing; synthetic oils; testing; impregnation of windings.

DIVISION OF ELECTRICAL INSTALLATIONS

Course Content and Demonstration Materials

General Course (I)

Installation material, regulations. Earthing cable with coupling box, distribution, centres, rubber insulated cables, location of cables, fluorescent lamps from the standpoint of installation, laws and regulations, safety regulations, low-voltage installations, life and fire hazards.

Electrical calculations of transmission lines. Concepts of power and energy, load curves, symbolic load curves, different energy distribution systems, calculations of voltage drop, calculations of losses, circle diagrams, voltage regulation, leakage, corona, economical current density, economical voltage, communication interference and stability problems.

Overloading, substations, tariffs. Overcurrents: calculation methods, numerical example, current limiting methods, temperature and mechanical effects. Protective relays: current transformer coupling, generator, transformer, and line protection. Voltage surges: protection against voltage surge, insulation standards. Production of electrical energy: utilization of Sweden's power resources, water power stations, water regulation, dams, power plant buildings, rotating machinery, transformers. Switchboards: diagrams of connexion, circuit breakers, switches, voltage surge protection. Control systems: control room equipment, remote control equipment. Storage batteries: different types, charging systems. Assessments: overhead charges, establishment of assessments, tariff limits.

Mechanical line calculations. Illumination. Mechanical line calculations: conductors, insulators, towers, use of power line standards, vibration of conductors. Illumination: concepts and units in lighting technique, the eye and the sense of sight, general demands on good lighting, photometry, nature and generation of light, sources of light, lighting fixtures, choice of light source and fixture, calculation methods, the planning and practical installation of illumination systems, maintenance, lamps, light and other radiations for special purposes.

Lecture	Equipment	Total cost in dollars
Installations	Demonstration material presented by different companies	—
Calculation of transmission lines	Model demonstrating mechanical stability	200
	Printomaxigraph	1,000
	Simple direct current network model .	500
Overcurrents, substations	High-voltage cathode-ray oscillograph .	7,500
	Relay demonstration apparatus . .	—
	Total	9,200

General Course and Special Course Combined (II)

Illumination: Technical concepts and units relating to light and illumination, the eye and the sense of sight, common necessity for good lighting, photometry, measurement of colour, the nature and production of light, the laws of radiation, sources of light,

lighting fixtures, selection of source of light and lighting fixtures, calculation methods, the planning, practical installation, and maintenance of illumination systems, lamps, light and other radiation for special purposes.

Calculation of mechanical features of overhead lines: General history; calculation of mechanical factors of overhead lines, including methods of calculation, conductors, insulators, towers and poles, the standards for overhead lines and their applications, safe crossings, general procedure for the construction of power lines, vibration of overhead lines; complete numerical example illustrating the mechanical design of overhead lines.

Storage batteries: Lead-acid storage battery, function and equipment, other storage batteries, function and equipment, charging and discharging equipment, dry cells.

Installations: Earthing cable with coupling box, distribution centres, rubber-insulated cables, location of cables, fluorescent lamps from the installation standpoint, low-voltage installations, life and fire hazard.

Electrical calculations of transmission lines: Load curves and load factor, energy distribution systems in general, calculation methods for electric power lines, exact calculation methods for long lines, voltage drop with unsymmetrical load under different conditions, voltage regulation methods, phase compensation, leakage and corona, generation and use of high-voltage direct current, economical dimensioning of high-tension transmission lines.

Overcurrents: Loading of lines from the temperature standpoint, calculation methods for overcurrents, heating effects and mechanical forces of overcurrents, relay protection (generator protection, transformer protection, complete generator-transformer protection, line protection), surge voltages and protection against them, insulation standards.

Switching equipment, tariffs, etc.: Power distribution, steam power stations, Diesel-driven electrical power stations, long-distance power distribution, atomic power plants, tide-water power plants, water power stations including water supply, flood control, dam construction, waterways, types of power stations, power plant buildings, water turbines, generators, and transformers from the maintenance point of view.

Switchgear including circuit breakers, isolators, switchboard sections, voltage transformers, busbars, insulators, bushings, surge protectors, synchronizing devices, relay systems, switchboards, communication and remote control, protective means, auxiliary power systems, compressed air installations, automatic control, complete plans of stations, construction of switchgear plants, stations for local distribution, assessments, the influence of overhead costs on assessments and tariff limits.

Lecture	Equipment	Total cost in dollars
Illumination	Box with different glasses and opal glass for testing persistence of vision and glare	15
	Picture illuminated with variable light intensity	3
	Lamps and fluorescent lamps of different types and colours	65
	Beam lights	15
	Stroboscopic effect with electrical record player	5
Overhead power line from the mechanical point of view	Models of towers, non-symmetrical spans, and spans with additional loads . .	—
Storage batteries	Demonstration material presented by different companies	—
Installations	Same as for the general course	200
Calculation of transmission lines	Same as for the general course . . .	1,700
Overcurrents	Same as for the general course . . .	7,500
Switching equipment	Duty-cycle meter	—
	Double tariff meter	—
	Total	9,503

EXERCISES AND PROJECTS

General Course (I)

The pupils taking this course have to work out the following projects:
Complete illumination plan for a street;
A simplified electrical installation in an apartment house with economic calculations;
Technical economic calculations of an electrical transmission system;
Planning of a simple transformer station with protective equipment.

General Course and Special Course Combined (II)

The pupils taking Course II have to work out numerical exercises on assessment problems and on general economic problems concerning installations, together with the following projects:
The mechanical dimensioning of an overhead line;
Plan for street illumination;
Complete electrical installation in an apartment house, with economic calculations;
Technical and economic calculations of electric high-tension power transmission;
Simple calculation of a small water-power station with switching plant, protection, and auxiliary equipment.

PRACTICAL WORK

The following practical work is accomplished by the pupils of Course II.

Quantity	Item and characteristics	Total cost in dollars
	(a) Power transmission over a simulated line with a generator at each end	
1	Motor-generator assembly:	
	D.C. machine, shunt, 5.6 kW, 7.5 H.P., 220 V, 1,230-1,500 r.p.m., 29 A	200
1	Synchronous generator, 4.5 kVA, 1,500 r.p.m., 230 V, 11 A	250
1	Auxiliary machine for magnetization currents	40
1	Induction regulator, 50 kVA	300
1	Switchboard, 4 sections:	
	Section I:	
	1 voltmeter and ammeter	75
	1 regulating resistance, 1 magnetization rheostat	65
	Section II:	
	1 voltmeter, 1 ammeter, 1 kilowattmeter, 1 reactive kilovolt-ampere meter	125
	1 synchronoscope, 1 phase indicator	100
	1 magnetization rheostat	50
	Section III:	
	Simulated line inductances and resistances	50
	Section IV:	
	1 voltmeter and ammeter	50
	1 kilowattmeter, reactive kilovolt-ampere meter, cos φ meter	150
	1 mechanism for operating induction regulator	50
	Total	1,505
	(b) Investigation of several common types of relay protection: ASEA's RI relay, constant time relay, and impedance relay	
1	Impedance relay	50
1	Inverse time-lag relay	50
	Carried forward	100

Quantity	Item and characteristics	Total cost in dollars
	Brought forward	100
1	Independent time-lag relay	75
1	Auxiliary relay	25
2	Current transformers	300
1	Synchronous clock	75
1	Variable transformer	125
1	Induction regulator	125
2	Ammeters	250
2	Voltmeters	
	Total	1,075

(c) Measurements on several common energy meters: kilowatt-hour meter, ampere-hour meter

1	Kilowatt-hour meter, three-phase	25
1	Kilowatt-hour meter, single-phase	25
1	Precision wattmeter	150
1	Current transformer	150
1	Variable transformer	375
2	Ohmmeters	25
1	Induction regulator, 120 V	75
	Total	825

(d) Investigation of the disruptive strength of several common insulating materials and stress distribution over a high-tension insulator chain

1	High-voltage transformer, 400/0.4 kV	25,000
1	Induction regulator, 50 kVA, 0-440 V	
	Relays and coupling apparatus	
1	Control room with instrument panels	
	Total	25,000

(e) Light measurements comprising light pattern curves of a light fixture, measurements of efficiency in a spherical photometer, and light intensity of a cinematographic lamp, investigation of the starting behaviour and operation data of a mercury discharge lamp

2	Ulbricht spheres	2,750
1	Voltmeter, mirror galvanometer, photocell	375
1	Light fixture (to be measured)	10
1	Mirror apparatus	1,250
2	Voltmeters, photocells, and light-spot galvanometers	750
1	Cinematographic lamp	5
1	Photometer panel	500
2	Voltmeters	300
1	Flicker photometer	150
1	Mercury discharge lamp	5
1	Colour compensated photocell	50
1	Wattmeter, ammeter	300
	Total	6,445

DIVISION OF TELEGRAPHY AND TELEPHONY

Course Content

General Course

Circuit theory: fundamental concepts and mathematical techniques; general four-terminal network theory; frequency transformations; filter circuits; cables considered as four-terminal networks; amplifiers considered as four-terminal networks.

Telegraph and telephone technique: telegraph technique; telephone technique; teletransmission technique.

Special Course

Circuit theory: continuous non-homogeneous transmission media considered as four-terminal networks; electromagnetic radiation; the transmission problem handled by matrix algebra; computation of pulse response in electrical filters; circuit equivalent of a commutating rectifier modulator; discontinuous non-homogeneities in cables.

Telegraph and telephone technique: theory of speech transmission; teletraffic technique; technique of telephone networks; relay computations; relay circuit technique.

These courses are completed with ex-programme lectures bearing on particular subjects chosen in telegraph and telephone technique.

Exercises and Projects

General Course
Numerical problems to follow up the lectures on circuit theory.

Special Course
Relay design, traffic problem, filter design.

Practical Work

Quantity	Item and characteristics	Total cost in dollars
General Course (70 students)		
(a) Measurements on filters		
1	Filter (object to be measured): a box containing six shielded toroid coils and condensers for internal connexions to two identical filter sections of low pass, high pass, band pass, or band suppression type, 8 possibilities	150
1	RC-oscillator, 0.02-200 kc/s, outputs 30 V-3 mV, 4, 8, 15, 200, 500 and 5,000 Ω	145
1	Valve voltmeter, 0.02-200 kc/s, 5 mV-250 V	290
1	Bridge for measurement of attenuation	75
1	Transformer, shielded and balanced, 600 Ω, 0.05-10 kc/s	100
1	Standard attenuator, 2 × 300 Ω, output impedance 600 Ω	375
1	Amplifier, 40 db output, cathode-follower with 600 Ω impedance	100
1	Decade resistor, 5 decades, 1,000 Ω × 10, 100 Ω × 10, 10 Ω × 10, 1 Ω × 10, 0.1 Ω × 10	90
1	Impedance-measuring bridge	510
1	Low-pass filter, variable cut-off frequency, f_2 = 0.26 kc/s, f_2 = 12 kc/s	400
	Total	2,235

Quantity	Item and characteristics	Total cost in dollars
	(b) Measurements on a two-wire repeater	
1	Two-wire repeater, mounted on a laboratory rack	500
1	Power supply to repeater	175
1	RC-oscillator, same as above	145
1	Standard attenuator, to 1 Mc/s	400
1	Transformer, shielded and balanced, 800 Ω, 0.02-6.5 kc/s	100
1	Valve voltmeter, 10 mV-300 V	95
1	Valve voltmeter, 0.02-200 kc/s, 5 mV-250 V	290
1	Decade resistor, 100 Ω × 10, 10 Ω × 10, 1 Ω × 10, 0.1 Ω × 10	90
1	Decade resistor, 1,000 Ω × 10, 100 Ω × 10, 10 Ω × 10, 1 Ω × 10, 0.1 Ω × 10	90
1	Cathode-ray oscillograph, 0.002-2 kc/s	375
1	Simulated line box, 1 cable, 7 pupin sections, impedance 2,000 Ω, 1 cable, 1 pupin section 2,000 Ω, 1 Hoyt balance	150
1	Simulated line, Z = 600 Ω	90
	Total	2,500
	(c) Measurements of the characteristic constants of a line	
1	Cable (object to be measured): 22 lengths of 900 m capacity-balanced Dieselhorst-Martin quad, pupin coils 27/11 mH, S_o = 1,800 m	—
1	Decade oscillator, 0.02-100 kc/s, output voltage and power amplifier, frequency stability 1%	625
1	Low-pass filter, variable cut-off, f_2 = 0.26 kc/s, f_2 = 12 kc/s	400
1	Transformer: special differential transformer for bridge measurements, 1.1-6 kc/s	150
1	Broadband amplifier	150
1	Power supply to above amplifier	100
1	Decade resistor, 1,000 Ω × 10, 100 Ω × 10, 10 Ω × 10, 1 Ω × 10, 0.1 Ω × 10	90
1	Air capacitor, calibrated, 58-1,520 pF	200
1	Mica capacitor, 3 decades, 1 μF, second grade	580
1	Telephone receiver	20
	Total	2,315
	(d) Acoustics	
1	Echo-free room, 7.5 × 4.5 × 3.2 m/1 m thick rock wool sound-proofing, isolated, only for demonstration	—
1	Sound-proof chamber, 3.5 × 2 × 2 m	—
1	Level indicator for rapid fluctuations, 750 db	1,150
1	Beat-frequency oscillator with wobbling tone and compression amplifier for maintaining constant sound amplitude	855
1	Zone-speech-audiometer with speech level indicator and frequency curve control and arrangement for determination of differential sensitivity	825
1	Record player	125
1	Records, special recording with three-digit test and monosyllabic words test with calibration signal and constant level	50
1	Condenser microphone	595
1	Amplifier for above microphone with indicator	110
1	Valve voltmeter, 20 c/s-3 Mc/s, 5 mV-500 V	290
—	Attenuators, 30 × 1 db	65
1	Pressure chamber, 6 and 2 cm^3	10
2	Moving coil telephone receivers	40
1	Crystal telephone receiver, type Brush	10
1	Magnetic telephone receiver, 2,000 Ω	10
1	Magnetic telephone receiver to hearing apparatus, 120 Ω	10
	Total	4,145

Quantity	Item and characteristics	Total cost in dollars

Special Course (30-40 students)

(a) Time measurements in telephone relays

1	Test relay on a plinth with arrangement for current and voltage measurements, also reversing switch and rheostat for the demagnetization of the core	10
1	Auxiliary apparatus for time measurement between two auxiliary relays, also calibration arrangement	100
1	Fluxmeter	550
1	Stopwatch for calibrating	25
—	Variable resistors, 75 and 150 Ω	65
1	Non-inductive decade resistor	90
1	Decade capacitor, 0.1 × 10, 1 × 10 μF	75
1	Variable inductance	65
1	Voltammeter	50
	Total	1,030

(b) Measurement of capacitive unbalance, capacitance balancing

—	Test cables, 25 samples, quads 150 m	—
1	Capacitive unbalance meter	875
1	Oscillator, 0.8 kc/s	75
1	Selective amplifier, 0.8 kc/s	75
—	Balancing capacitors	25
—	Magnetic telephone receivers, 2,000 Ω	10
	Total	1,060

(c) Investigation of modulated centimetre wave receiver

1	Modulated centimetre wave receiver	500
1	Beat-frequency oscillator	675
1	RC-oscillator, same as under (a) of the general course	145
1	Power supply for above	75
1	Voltammeter	50
1	Distortion variator, amplifier with diode clipping	25
1	Regulated power supply	175
1	Distortion meter	500
1	Cathode-ray oscillograph	260
	Total	2,405

(d) Determination of defect in a pupin cable by means of impedance measurements

1	Pupin cable, same as under (c) of the general course	—
1	Hoyt balance	150
1	Decade oscillator, same as under (c) of the general course	625
1	Differential transformer, same as under (c) of the general course	150
1	Wide band amplifier with power supply, same as under (c) of the general course	250
1	Air capacitor, same as under (c) of the general course	200
1	Mica capacitor, same as under (c) of the general course	580
1	Decade resistor, same as under (c) of the general course	90
1	Telephone receiver, same as under (c) of the general course	20
1	Low-pass filter, same as under (c) of the general course	400
	Total	2,465

Quantity	Item and characteristics	Total cost in dollars
(e)	Investigation of the driving mechanism of a pulse driven selector for automatic telephone system	
1	Step by step selector, with stand for indicating lamps and self-driven relay	50
1	Pulse generator, with controlled speed motor driving a collector which continuously varies the pulse width	200
2	Voltammeters	100
1	Tachometer	60
1	Battery, 6 V	30
	Total	440
(f)	RC-oscillator	
1	RC-oscillator	100
1	Regulated power supply	175
1	Variac	40
1	Voltmeter, 10 V	50
1	Cathode-ray oscillograph, same as under (b) of the general course	375
1	Vacuum-tube voltmeter, same as under (a) of the general course	290
1	RC-oscillator, same as under (b) of the general course	145
1	Wave analyser	770
	Total	1,945

DIVISION OF RADIO-ELECTRICITY

This division is composed of three sections dealing respectively with radio-electricity proper, V.H.F. techniques and electro-acoustics. Two associate professors are in charge of the two latter sections (see the section on "Teaching staff", p. 89).

RADIO-ELECTRICITY

Course Content

General Course

Introduction; survey of the applications of radio techniques: amplifiers, transmitters, receivers, etc.; principles of broadcasting, television, radio communication, radar, and navigation systems.

Simple impedance elements: resistors, coils, and capacitors; approximations with parallel connexion of reactances and resistances of different magnitudes; common non-linear components.

The simple tuned circuit: tuned circuits with continuous wave, standardization, and characteristic magnitudes; series and parallel resonance.

Coupled circuits: general relationships; reduction to equivalent circuits; matching by adjustment of coupling; tuning to one of two coupled circuits, coefficient of coupling, optimum coupling, conditions for maximum efficiency and selectivity; coupling of two tuned circuits.

The audio-frequency transformer: matching transformer: the ideal transformer, high- and low-frequency limitations, equivalent circuits; effect of losses and distributed capacitance; the power transformer and its characteristics.

Modulated continuous wave: amplitude, phase, and frequency modulation, carrier and sidebands; pulse modulation; frequency conversion; demodulation.

Antennas and wave propagation: radiation from dipoles and straight antennas; plane electromagnetic wave, ground wave and sky wave, the properties of the ionosphere; current distribution, effective antenna height and radiation resistance for simple antennas; feeders.

Electro-mechanical conversion: different principles for converting electrical oscillations to acoustic and vice versa; different kinds of microphones, telephones, loudspeakers, and other electro-acoustical apparatus.
Fundamentals of electron valves: diodes, triodes, and pentodes; the characteristics of linear amplifiers, equivalent circuits, working diagrams.
Low-frequency amplifiers: resistance coupling, the effect of tube capacitances; grid resistor and capacitor, cathode resistor and by-pass capacitor; transformer- and impedance-coupling; direct current amplifiers.
High-frequency amplifiers: selective amplifiers and broadband amplifiers; the effect of grid-anode capacitance; non-linear phenomena in high-frequency amplifiers; valve noise; amplification control.
Output amplifiers: class A amplifiers, choice of operation point and load with regard to output and distortion; push-pull amplifiers; class AB and class B.
Transmitter amplifiers: class B and class C; frequency multiplication.
Feedback: feedback and feedback factor; positive and negative feedback; current and voltage feedback; improvement of amplification characteristics through degenerative feedback; regeneration by means of positive feedback.
Oscillators: feedback oscillators, different oscillator circuits; aperiodic oscillators and relaxation oscillators; generation of different wave forms.
Modulation and demodulation: methods of modulating in transmitters; mixing and detection; simple system for frequency modulation.
Direct current power supplies: rectifiers and rectifier tubes, rectifier circuits; filtering and stabilization.
Transmitters and receivers: fundamental construction of radio transmitters and receivers; automatic control of amplification and frequency; systems for broadcasting, radio communication, and radio navigation; radio disturbances, noise, etc.; bandwidth and frequency problems.
Special applications: brief survey of high-frequency heating, pulse technique, microwave technique, television, radar, etc.

Special Course

More detailed treatment of certain more important sections of the course: detectors, power rectifiers; amplifiers in classes A, B and C; non-linear phenomena in amplifier tubes; circuit noise and valve noise; degenerative feedback; mixer valves; methods for amplitude modulation; methods for frequency modulation; antennas and wave propagation; receiver techniques; transmitter techniques.

EXERCISES AND PROJECTS

Numerical and construction problems are given to the pupils. They bear more particularly on the design and the construction of a radio receiver or amplifier and a transmitter.

PRACTICAL WORK

Quantity	Item and characteristics	Total cost in dollars
General Course (70 students)		
(a) Investigation of a simple tuned circuit and two coupled tuned circuits		
The figure of merit, Q, is measured and computed by several methods. A resonance curve is taken for over-critical coupling.		
1	"Breadboard" set-up consisting of circuits, amplifier tubes, diodes, high-frequency oscillator, etc.	200
1	Oscillograph with built-in frequency modulated oscillator for direct registration of bandpass curves for coupled circuits	375
1	Thermocouple instrument	125
1	Q-meter	875
	Total	1,575

Quantity	Item and characteristics	Total cost in dollars

(b) The taking of characteristic curves for valves

Characteristic curves for triode-, tetrode-, and pentode-coupled valves are taken. Optimum operating points and load-lines for the valves are determined.

1	"Breadboard" set-up with power supply, 8 m	350

(c) Investigation of vacuum tube rectifiers

Load curves are drawn for both choke-input and capacitor-input filters, and measurements are made of hum, efficiency, etc. The filter capacitor charging current and voltage are studied.

1	"Breadboard" set-up for demonstration of circuits and measurements according to a given schematic diagram	100
1	Valve voltmeter	325
1	Double-beam oscillograph	375
1	Wattmeter	75
	Total	875

(d) Investigation of audio-frequency amplifiers

Frequency response curves, amplification, and output impedance are investigated with different data for the input, first without degenerative feedback and then with current- and voltage-degenerative feedback.

1	"Breadboard" set-up for demonstration of circuits and measurements according to a given schematic diagram	100
1	Signal generator	150
2	Valve voltmeters for audio-frequencies	225
	Total	475

Special Course (30-40 students)

(a) Investigation of non-sinusoidal wave forms

Investigation of multi-vibrators, differentiating and integrating networks, and cathode followers.

—	Several "breadboard" set-ups	50
1	Signal generator, square wave	250
1	Double-beam oscillograph	375
1	Valve voltmeter	325
	Total	1,000

(b) Investigation of oscillators

An oscillator's grid current, plate current, plate power, output power and efficiency under different loads are measured. The effect of the L/C ratio upon efficiency is investigated.

1	"Breadboard" set-up with an oscillator	75
1	Variable load resistance	5
3	Thermocouple instruments	50
1	Absorption wavemeter	75
	Total	205

(c) Distortion measurements

Comparison of a triode with a pentode under different load and power output conditions.

1	"Breadboard" set-up with amplifier and power supply	100
1	Signal generator, distortion less than 0.2 %	150
1	Distortion meter for one frequency	450
1	Valve voltmeter	110
—	Several load resistors	10
	Total	820

Quantity	Item and characteristics	Total cost in dollars

(d) Measurements on antennas and transmission lines

Standing wave relationships on transmission lines. Directional antennas. Current distribution along different antennas. Directional characteristics. Impedance at the feeding point.

Quantity	Item and characteristics	Total cost in dollars
—	Several antennas	20
1	Field-strength meter	30
1	Transmitter for 112 Mc/s	90
1	Transmitter for 50 Mc/s	50
1	Valve voltmeter	55
1	Current indicator for antennas	40
	Total	285

(e) Investigation of radio receivers

Sensitivity, image frequency relationship, fidelity curve, amplification in the different stages.

Quantity	Item and characteristics	Total cost in dollars
—	Radio receivers	75
1	"Chanalyst"	200
1	Signal generator	525
1	Output power meter	175
1	Signal generator	90
	Total	1,065

(f) Investigation of plate-modulated class C amplifier

Measurement of plate current, grid current, power output, efficiency, etc., for various plate voltages, H.F. driving, and grid bias. Modulating with 50 c/s and investigation of the linearity, etc.

Quantity	Item and characteristics	Total cost in dollars
1	"Breadboard" set-up with class C amplifier	200
	Drive stage for above	200
1	Vacuum tube voltmeter	55
1	Oscillograph	350
	Total	805

V.H.F. TECHNIQUES

Course Content

Special Course

Transmission line theory: fundamental equations, reflection, standing waves; the impedance circle diagram; transmission lines with continuously variable parameters.

Wave guides: plane electromagnetic wave, boundary conditions; rectangular, circular, and elliptical wave guides; co-axial cables as wave guides; attenuation, matching, discontinuities. Conception of impedance, analogy to two-conductor system.

Resonators: the transmission line resonator, the cavity resonator, the wave guide resonator, other types.

Antennas: directivity, absorption surface; the radio equation, the radar equation; directional antennas with half-wave elements, radiation patterns; parabolic reflectors, horn antennas, slot antennas, dielectric antennas.

Wave propagation: reflection, refraction, divergence, and attenuation; computation of field strength.

Electronic valves: U.H.F. phenomena in diodes and grid control tubes; tubes with plane electrodes; the resnatron; tubes with inductive output; retarding field oscillator; velocity modulation and reduction of transit time; double resonant cavity klystron, reflex klystron; magnetrons: parallel plane electrode system; cylindrical electrode system, different modes of oscillation; cavity magnetron.

Technique of measurements: crystal rectifiers, bolometers, thermistors; directional coupler and the magic T; the measurement of frequency, power and attenuation, impedance and constants of the materials.
Micro-wave links and other technical applications.

PROJECTS

This course is completed with numerical exercises, construction problems and demonstrations.

PRACTICAL WORK (30-40 students)

Quantity	Item and characteristics	Total cost in dollars
	(a) The measurement of reflection and characteristic impedance in wave guides (3 cm wavelength)	
	The measurement of impedance with the help of a standing wave meter and an impedance diagram according to Smith. Impedance matching with the aid of reactance (sliding screw tuner). Computation of that reactance as well as measurement of it.	
1	Signal generator, 3 cm	100
1	Standing wave meter	375
1	Sliding screw tuner	50
—	Several wave guides, matched terminals	25
	Total	550
	(b) The magic T (3 cm wavelength)	
	Impedance matching with reactances (sliding screw tuner) and testing the match with a standing wave meter. Measurement of impedance: the impedance of the device to be measured is computed from the reflection coefficient, whose absolute value and phase angle are measured. The measurement of power: the measurement of attenuation in an attenuator.	
1	Signal generator, 3 cm	100
1	Standing wave meter	190
2	Sliding screw tuners	100
1	Magic T, not matched	45
2	Attenuators	100
1	Short-circuit plunger	25
1	Crystal detector	25
	Total	585
	(c) Rieke diagram for magnetrons (10 cm wavelength)	
	Measurements are made for the purpose of locating on the impedance diagram the load impedances for which the magnetron gives a constant power output or a constant frequency. The loading is done through a transformer followed by a power termination. Impedance measurements with a standing wave meter. Power and frequency measurements with a directional coupler.	
1	Modulator for magnetrons	125
1	Magnetron	25
1	Coupler between magnetron and wave guide	40
1	Directional coupler, 27 db	—
1	Standing wave meter	250
1	Transformer	75
1	Power load	80
1	Frequency meter, absorption	85
1	Power meter	20
	Total	700

Quantity	Item and characteristics	Total cost in dollars

(d) Measurements on a klystron (3 cm wavelength)

Determination of the mode of oscillation in a reflex klystron as a function of accelerator and reflector potentials. The variation of frequency with reflector potential is investigated.

Quantity	Item and characteristics	Total cost in dollars
1	Reflex klystron	20
1	Crystal detector	20
1	Resonator, X-band	25
—	Several wave guides	25
	Total	90

(e) The reflection of plane waves (10 cm wavelength)

Polarization. Reflection from a conducting plane. The variation of the electrical field strength with distance from the plane is measured with an antenna probe. The determination of the position of the minima as a function of the angle of incidence of the wave. The determination of wavelength.

Quantity	Item and characteristics	Total cost in dollars
1	Klystron	—
1	Antenna horn	50
1	Reflecting plane with antenna probe	125
1	Klystron power supply	500
	Total	675

N.B. In addition to this equipment the students also use some power supplies and some micro-ammeters for measuring crystal detector currents.

ELECTRO-ACOUSTICS

Course Content

Special Course

The ear and the sense of hearing from the technical standpoint. The general nature of speech and music sounds.
Sound waves. Sources of sound and their directional characteristics.
Applications of electro-technical computation methods to mechanical and acoustical oscillations. Mechanical and acoustical impedance. The fundamental equations for linear electro-mechanical systems.
Loudspeakers and microphones.
Methods of reproducing sound. Supersonics. Electro-acoustical measurements.

Exercises

Numerical exercises are given to the students as a complement to the course.

Practical Work (30-40 students)

Quantity	Item and characteristics	Total cost in dollars

(a) Measurements on a microphone and a loudspeaker in a sound-proof room

The deviation of the sound-proof room from the ideal is investigated. Audio-frequency curves for a microphone and a loudspeaker are taken, for the microphone in both loaded and unloaded conditions and with different angles of incidence.

Quantity	Item and characteristics	Total cost in dollars
1	Condenser microphone	400
1	Signal generator, volume indicator, microphone amplifier, variable amplifier	3,750
—	Microphones and loudspeakers	50
	Total	4,200

Quantity	Item and characteristics	Total cost in dollars

(b) Measurements on a cone-type loudspeaker

The loudspeaker's impedance over the audio-frequency range is measured first when the loudspeaker is dismounted, and then when it is mounted in an open or a cloud box or in a base-reflex chamber. The distortion is measured.

1	Impedance bridge	625
1	Signal generator	150
1	Base reflex box	15
1	Distortion meter for several frequencies	625
	Total	1,415

N.B. In addition to the equipment listed above, which is used by the three sections, the students have at their disposal 10 universal instruments, 4 variable regulated power supplies 400 V, 150 mA, two larger power supplies, 1 for 1.5 kV, and 3 variable transformers 0.25-0.5 kVA.

DIVISION OF ELECTRICAL MEASUREMENTS

Course Content

General Course

Fundamentals of the techniques of electrical measurements.
Theory of deflectional instruments.
Measurement of current, voltage, charge, magnetic flux, and power.
Impedance measurements, bridges for direct and alternating current, grounding, shielding, and balancing.
Recording instruments and oscillographs.
Purpose, theory, and use of instrument transformers. Measurement of transformer's turn ratio error and phase angle error. Instrument transformers for direct current.
Measurement of phase angle, power factor, reactive and apparent power. Synchronoscope. Phase indicators.
General principles of testing electrical machines and transformers.
Energy meters for direct and alternating current, their theory and construction.
Insulation measurements and protection on cables and installations against faults.

Special Course

Construction of standard elements, instruments, and apparatus for use in technical measurements. Contacts and relays. Ageing. Measurement amplifiers.
Oscillography.
Use of electrical methods to measure non-electrical quantities, such as linear dimensions, revolutions, and speed.
Vibration and strain measurements.
Material testing, e.g. detection of cracks. Analysis.
Instruments and methods of measuring used in chemistry, medicine, etc., e.g. *p*H-meters, electro-cardiographs, electronic counters.
Electron microscopes. Navigation instruments. Computers.
Organization of measurements. Experimental errors.
Determination of accuracy.
Planning of laboratories.
Economic problems.

PRACTICAL WORK

Quantity	Item and characteristics	Total cost in dollars

General Course (for 70 students working by groups of two; one part of these groups performs the experiments during the first semester, the other during the second semester).

(a) Voltmeters

Comparative investigation of different types of instruments for D.C. and A.C.; investigation of the frequency characteristics of A.C. instruments.

1	Standard instrument, D.C., 10 Ω	150
—	Input coupling resistors for the above	75
1	Voltmeter,[1] dynamometer	225
1	Voltmeter, moving iron	75
1	Voltmeter, moving coil	100
1	Voltmeter, universal instrument	100
1	Voltmeter, hot wire	—
1	Voltmeter, valve, A.C. and D.C.	100
1	Oscillograph	150
1	Signal generator	75
1	Potentiometer, 400 W, 2.5, 600 and 630 Ω	30
	Total	1,080

(b) Voltage measurements with a valve voltmeter

Connexion of a valve voltmeter with a diode and with a triode in a cathode follower circuit according to a given schematic drawing, and also a consideration of their characteristics.

1	Valve voltmeter	200
1	Decade condenser, 11.1 μF	65
1	Decade resistor, 0-100 kΩ	25
1	Oscillograph (Waterman's pocketscope, D.C. amplifier)	225
1	Universal instrument	100
1	Milliammeter, 5 mA	25
—	Valves, valve sockets, voltage dividers, power supply	—
	Total	640

(c) Cathode-ray oscillograph I

Fundamental concepts concerning the oscillograph's construction and operation. For demonstration purposes an oscillograph tube is used together with its circuit elements completely visible on an open panel.

1	Demonstration oscillograph	constructed at the institute	500
1	Transitron-coupled sweep generator		
1	Sweep generator with thyratron and amplifier		
1	Sweep generator with glow discharge tube		
—	Power supply		
—	Magnetic deflection coils		
1	Signal generator		75
1	Universal instrument		100
1	Bell transformer, anode batteries		—
	Total		675

[1] All the voltmeters have approximately the same range.

Quantity	Item and characteristics	Total cost in dollars

(d) Cathode-ray oscillograph II

Use of the oscillograph for frequency determination by external synchronization, Lissajous' figures, modulation of the electron beam; use of the oscillograph for the measurement of inductances and capacitances.

1	Oscillograph with X- and Y-amplifiers and Z-modulation	300
1	Signal generator with symmetrical output	150
1	Standard inductance, 0.1 H	50
1	Decade resistance, 0-100 kΩ	25
1	Decade resistance, 0-100 MΩ	25
1	Mica condenser, 1.0 μF	50
1	Mica condenser, 0.001 μF	15
	Total	615

(e) Cathode-ray oscillograph III

The study of two phenomena simultaneously with double beam oscilloscope (beam switching); the photographing of the separate traces.

1	Oscillograph	425
1	High-voltage power supply for the above	125
1	Electron coupler	125
1	Camera	150
1	Signal generator	75
—	Capacitor, 0.01 μF, choke 7 H, resistor 10 Ω, key, circuit breaker, anode batteries	—
	Total	900

(f) Measurement of small resistances

Comparison method; Thomson bridge method; volt-ammeter method.

1	Reflecting galvanometer	100
1	Millivoltmeter	75
1	Voltmeter, 10 Ω	150
1	Shunt for the above	40
2	Decade resistors, 0.1-10,000 Ω	175
1	Decade resistor, 0-100 kΩ	25
1	Standard resistor, 0.001 Ω	25
1	Standard resistor, 0.1 Ω	25
1	Variable resistor, 6 Ω	20
10	Fixed resistors, 5 of 1 Ω and 5 of 10 Ω	5
—	Circuit breaker, reversing switch	—
	Total	640

(g) Measurement of medium-value resistances

Measurement of resistance of incandescent lamps with Wheatstone bridge; determination of resistance by the volt-ammeter method, and the drawing of characteristic curves for iron-hydrogen resistances; determination of start- and extinction-voltage and plotting of current-voltage graph for glow-discharge lamp; determination of resistance of a selenium rectifier in forward and reverse directions.

2	Universal instruments	200
1	Decade resistor, 0-100 kΩ	25
1	Reflecting galvanometer, 10 Ω	125
1	Potentiometer, 1,000 Ω	75
—	Selenium rectifier, fixed resistor about 6,000 Ω, key, lamp sockets, batteries, lamps, ballast tubes	—
	Total	425

(h) Measurement of large resistances

Valve voltmeter method; teraohmmeter method (electrometer tube whose grid bias is regulated by voltage division between the unknown resistor and a known resistor, and whose I_a-V_g diagram is known; instrument in the anode circuit).

Quantity	Item and characteristics	Total cost in dollars
1	Teraohmmeter, constructed by the institute	75
1	Valve voltmeter	100
1	Megohmmeter	425
1	Decade resistor, 0-10 MΩ	25
1	Universal instrument	65
—	Transformer, variable resistor, 2 anode batteries	—
	Total	690

(i) Ballistic galvanometer

Measurement of the ballistic constant, current constant, and internal resistance of ballistic galvanometer.

Quantity	Item and characteristics	Total cost in dollars
1	Ballistic galvanometer, reflecting	200
1	Fixed capacitor, 10.5 μF	75
2	Decade resistors	125
1	Voltmeter, 10 ohmmeter movement	150
1	Stopwatch	40
—	Key, 2 dry cells 1.5 V	—
	Total	590

(j) Compensation measurement

Determination of e.m.f. in dry batteries in a simple compensation circuit with a bridge wire; calibration of ammeter in Feussner compensator.

Quantity	Item and characteristics	Total cost in dollars
1	Reflecting galvanometer	125
1	Feussner compensator	500
9	Variable resistors	75
1	Decade resistor	25
1	Ammeter, 10 Ω instrument	150
—	Shunts for the above	40
1	Standard resistor, 10 Ω	25
1	Standard element	40
1	Universal instrument	100
1	Potgalvanometer	25
—	Key, 2 dry cells 1.5 V, 2 storage batteries 2.6 V	—
	Total	1,105

(k) Curve analysis

Photographing with help of oscillograph of current, voltage, and power curves for circuit with phase shift, and iron measurement together with graphical analysis of these curves.

Quantity	Item and characteristics	Total cost in dollars
1	Oscillograph	2,500
1	Current transformer	75
1	Variac	55
1	Transformer	5
1	Ammeter, 0-1 A, 0-5 A	110
—	Variable resistor, fixed resistor	—
	Total	2,745

Quantity	Item and characteristics	Total cost in dollars

(l) Measurement of ground-point resistance

Trouble-"shooting" on cable with special bridge; comparison of different types of grounding with volt-ammeter method and A.C. bridge for measurement of ground resistance.

1	General-purpose bridge	100
1	Ground resistance measurement bridge	75
3	Universal instruments	300
1	Variac	65
1	Transformer, 220/10 V	25
2	Batteries, 6 V	—
1	Storage battery, 1.2 V	—
	Total	565

(m) Schering bridge

Measurement of cable capacitance with H.T. in Schering bridge with Wagner earth.

1	Wave analyser	1,050
1	Power amplifier	40
1	Signal generator	150
1	Universal instrument	100
1	Decade resistor, 0.1-10,000 Ω	75
1	Decade resistor, 1-100,000 Ω	150
1	Decade capacitor, 1.11 μF, 300 V	110
1	Variable capacitor, 46-1,030 μF	65
1	Ratio resistor, 2 × 0-1,000 Ω	75
1	Compressed gas condenser	375
1	Oil-filled transformer	250
1	Decade capacitor, 0.001-4 μF	125
1	Special bridge with galvanometer indicator	50
—	Transformer, choke	—
	Total	2,615

N.B. All the following laboratory exercises are repeated twice. The equipment listed below, however, applies to one laboratory group.

(n) Measuring bridge's convergence

Investigation of convergence conditions for an impedance measuring bridge, Maxwell II, with different initial values.

1	Signal generator	150
1	Balanced transformer	65
1	Ratio resistor, 2 × 0-1,000 Ω	75
2	Decade resistors, 0.1-10,000 Ω	150
1	Decade capacitor, 1.11 μF	65
1	Standard inductance, 0.5 H	25
1	Volt-ammeter	75
1	Valve voltmeter, lowest range 10 mV	210
	Total	815

(o) Measurement of phase angles

Investigation of phase shift in an unsymmetrical four-terminal network as a function of frequency, with cathode-ray oscillograph and with valve voltmeter.

1	Oscillograph with X- and Y-amplifiers	300
1	Valve voltmeter, lowest range, 1.5 V	125
1	Signal generator, 20-200,000 c/s	150
	Total	575

Quantity	Item and characteristics	Total cost in dollars

(p) Measurement of short time intervals

Measurement of on- and off-operating time under different conditions for a telephone relay by the determination of the change in charge of a capacitor. The charging takes place via a thyratron in a circuit which causes it to be conducting only during the relay's on- and off-interval.

1	Valve voltmeter, D.C.	100
2	Universal instruments	175
1	Telephone relay	—
1	Decade resistor	50
—	Filament transformer, keys, 10 μF capacitor, gas tetrode, keys, grid-bias battery, 2 anode batteries	—
	Total	325

(q) Measurement of distortion

Investigation of the line voltage's overtone contents by means of a wave analyser; the distortion in amplifiers with different load by means of a wave analyser.

1	Wave analyser	1,000
1	Universal instrument	75
1	Oscillograph with D.C. amplifier	225
1	Power amplifier, 10 W output	100
1	Square-wave generator	935
1	Octave filter	275
—	Capacitors and load resistors	—
	Total	2,610

(r) Measurements on starting battery

Terminal voltage, internal resistance, electrolyte's specific gravity and temperature in a lead-acid cell are checked under charge and discharge cycle. The internal resistance is measured partly by D.C. (compensator method), partly by A.C. (volt-ammeter method). The A.C. measurement can be done during charging or discharging.

1	Lead-acid storage battery	—
1	Ammeter, 10 Ω instrument	150
1	Shunt for the above	65
2	Universal instruments	175
1	Stopwatch	40
1	Valve voltmeter, 5 mV lowest range	175
3	Variable resistors	—
1	Load resistor, about 0.05 Ω	—
—	Capacitor, knife switch, thermometer, areometer, Ni-Fe storage battery	—
	Total	605

(s) Q-meter

Characteristic data for a coil with and without iron core and a variable capacitor are determined; dielectric constant and angle of lag in a dielectric are determined by placing a test sample between the plates of a condenser and obtaining data with and without the dielectric.

1	Q-meter	950
—	Coils, capacitors, insulating materials	—
	Total	950

(t) Permanent magnets

The drawing of hysteresis loops for test bars of magnetic steel in a yoke apparatus according to Neumann.

Quantity	Item and characteristics	Total cost in dollars
1	Yoke apparatus according to Neumann	125
1	Test magnet with coil	—
1	Fluxmeter, 15,000 Maxwell-turns/scale division	150
1	Ballistic galvanometer	200
1	Ammeter, 10 Ω instrument	150
5	Shunts for the above, 75-0.75 A	185
1	Universal instrument	75
—	Long solenoid, fixed resistor, 2-pole switch	—
	Total	885

N. B. The following problems (optional) may be given to the students in connexion with these practical works (a-t):

1. Measurement of distortion of an oscillator in the frequency range 0.01-1 c/s.
2. Determination of a variac's characteristic data. Show equivalent diagram, and also draw vector diagram and efficiency curve.
3. Measurement of a decade condensor's capacitance and angle of lag (Maxwell bridge).
4. Determination of impedance element in a mesh connected three-terminal network.
5. Measurement of the phase angle of several wire-wound resistors.
6. Determination of capacitance and angle of lag in a large electrolytic condenser.
7. Determination of valve characteristic with oscillograph.
8. Measurement of capacitance in rectifiers.
9. Calibration of flux meter.
10. Determination of exposure time in a camera.
11. Investigation of the linearity of the time axis of an oscillograph.
12. Investigation of two valve voltmeters' frequency dependence and characteristics with regard to the measuring voltage's wave form.
13. Construction of a frequency meter with help of a Wien bridge for the frequency 50 ± 2 c/s.
14. Construction of equipment for pulse-counting by means of photocell and telephone counter.
15. Investigation of frequency dependence of several rectifier instruments and analysis of the cause of the variations.
16. Construction of a "flip-flop" generator with a glow-discharge lamp.
17. Determination of the slip of an asynchronous motor with a cathode-ray oscillograph.
18. Investigation of contact resistance.

The equipment used is the same as that indicated in the preceding pages.

Special Course (25 students)

(a) Investigation with stroboscope of periodic and single sweep phenomena (photographing)

1	Stroboscope	450
	Total	450

(b) Practice exercises with double-beam oscillograph

The speed of sound in different media is determined with different sources and targets, the impulses of which are registered on the oscillograph.

1	Double-beam oscillograph	500
	Total	500

(c) Photocells

Investigation of photocells' general characteristics, together with an example of the use of photocells in relay circuits.

(d) Wire strain-gauge

Investigation of static and dynamic strain with a strain-gauge in a bridge circuit and with an oscillograph as indicator.

N.B. The laboratory exercises for the special course are worked out by a comparatively smaller number of students (about 25) and the apparatus is assembled for a short time only. As a result, they need less equipment than the exercises for the general course. In addition to the apparatus listed above, 2 asynchronous motors of 0.5 H.P. (total cost: 50 dollars) and a few common indicator apparatus, variable resistors, oscillographs, etc., are used.

DIVISION OF HYDRAULICS AND HEAT ENGINES

Course Content

General Course

Sources of energy. Primary and secondary movers. Survey of various types of hydraulic and thermal motors and their principles of action. Reciprocating engines and turbines. Hydraulics, laws of flow without and with losses, conversion of energy. Practical features of water turbine design. Impulse and reaction turbines, velocity diagrams. Theoretical efficiency, losses, specific speed. Working media for heat engines. Properties of gases and vapours and their thermodynamics under stationary and flow conditions. Heat diagrams, conversion of energy, heat transfer. Fuels and their combustion, heat losses. Practical features of the design of steam engines and turbines, internal combustion engines and hot air motors.

Special Course

Hydraulic motors:
Design principles of various types of hydraulic turbines and hydraulic governors. Operating characteristics. Regulation problems. Principles of design and equipment of hydraulic power plants.

Heat engines:
Steam production. Boilers with furnaces and accessories. Steam engines and their accessories, power plants, equipment, operation characteristics. Various types of internal combustion motors and hot air motors and their accessories, power plants, equipment, operation characteristics. Means for fuel saving, and reduction of installation costs. Heat and power combinations. Co-ordination of hydraulic and thermal plants.

Exercises and Projects

General Course

In connexion with this course, numerical exercises and construction problems bearing on fluid mechanics, thermodynamics, conversion of energy and combustion are given to the students.

Special Course

The exercises and projects bear on the planning of a thermal power plant (including calculation of power costs and choice of suitable types and sizes of equipment elements). Visits to hydraulic and thermal power plants and to workshops for the manufacture of hydraulic and thermal motors, during which demonstrations are made to the students, are also organized.

VARIOUS COURSES

Industrial Economics and Management

General Course

The principles of industrial economics and management; finance of industrial enterprise; costs, income and profit, organization and management of different industrial enterprises; administration and leadership, production planning and control, storekeeping, time and motion studies.
Course in industrial accounting, especially the principles and practice of modern Swedish accounting systems.

Special Course for Production Engineers

A more intensive course in production economics, management, planning and control, time and motion studies, physiology and psychology of work.

Special Course for Sales Engineers

A more intensive treatment of industrial economics, especially distribution of industrial commodities, sales organization, market analyses, advertising, transport, and office management.

Foundry Work and Welding

Special courses on foundry work and welding are also organized during the third year.

THIRD PART

HIGHER TEACHING OF ELECTRICITY IN GREAT BRITAIN

INTRODUCTION

The electrical industry is one of the largest branches of engineering activity in the United Kingdom, and the duties and qualifications of the industry's personnel vary widely. This article attempts to deal only with the education and training of the chartered (or professional) electrical engineer. The qualifications "chartered" or "professional" are not always used in conjunction with the term *electrical engineer* and their use is really necessary only to emphasize the point that it does not cover the other categories of personnel[1] who are qualified electrically and who may be broadly classified as *technicians* and *craftsmen*. The number of electrical technicians in relation to that of electrical engineers is at present approximately in the proportion of five to one.

So as to leave no doubt about the kind of person one should have in mind when one speaks of an electrical engineer, the term should be defined. The Institution of Electrical Engineers' definition is as follows: A (professional) electrical engineer is one who is competent through his education and training to assume personal responsibility for developments in electrical engineering; to apply the scientific outlook and method to the initiation, organization and supervision of technical work; to give authoritative technical advice; and to exchange ideas with his fellows for the general furtherance of science and its applications.

An electrical engineer may be engaged in a branch of electrical engineering varying from heavy electrical machinery to electronic or ultra-high-frequency devices, and his activities may range from sales engineering to fundamental research. His general and higher education, practical training and early experience, in which the Institution of Electrical Engineers requires certain standards, form a broad basis for subsequent technical and administrative responsibilities. Attainment of the degree of competence implied in the foregoing will necessarily demand personal integrity as well as initiative and intelligence.

There are two principal methods of obtaining the necessary higher education:

1. A full-time course (usually at a university) of three or four years leading to a degree or, less often, a diploma in electrical engineering.
2. A part-time course at a technical college of four or more years, leading ultimately to a Higher National Certificate in Electrical Engineering.

In conjunction with each of these methods of education an appropriate scheme of practical training is followed, namely:

A graduate apprenticeship lasting two years for those who have completed their full-time studies; in some schemes the first year of the apprenticeship may be served immediately before a student enters a university, leaving one year only of training after he has qualified.

A student apprenticeship lasting five years, for those who follow concurrent courses of part-time technical education.

The entrant to the electrical engineering profession will normally have obtained his early general education at either a secondary grammar or a public school. The

[1] These classes of personnel have been defined as follows: *an electrical technician* is a person who carries out in a responsible manner approved techniques which are either common knowledge amongst those who are technically expert in his branch of industry or specially prescribed by professional electrical engineers. These techniques are not those of the craftsmen, though they may involve manual skill; in many cases they include the skilled use of delicate and complicated instruments and may also require the intelligent and accurate use of approved methods of calculation. They involve practical experience of some limited branch of electrical engineering combined with the ability to complete the details of a project using well-established practice.

To become an electrical technician a person must have been educated to a standard at least, and preferably beyond, that of the Ordinary National Certificate in Electrical Engineering, and in addition must have had training and experience in the particular sphere of electrical engineering in which he hopes to work.

A craftsman, as in other fields of engineering, is one who is skilled in the carrying out of a range of manual and machine operations.

secondary grammar school is, with few exceptions, a day school and provides, free of cost, a general education up to the standard required for admission to a university; it is part of the statutory system of education. All children who at about the age of eleven show appropriate ability have the opportunity to enter a grammar school. Public schools are normally residential, although some provide only for day pupils; moreover they are in general wholly independent and are not part of the statutory system. The age of entry is about two years later than that to a secondary grammar school, but a general education up to a similar standard is provided.

It is not possible to say which of the two schemes of higher education and training mentioned above is the better; the correct choice for any single person is governed by his aptitude, interests and circumstances. The university course normally provides what may be termed the more broadly-based fundamental education in engineering and the associated sciences; but the student apprentice has the advantage of a more intimate acquaintance with practical engineering problems while receiving his higher education. Men of both types are required by industry—the one being regarded as complementary to the other—and both have equal opportunities for advancement to positions of senior responsibility.

A third type of apprenticeship is available in which the student spends alternate periods of about six months each in practical training and at a college. Such schemes, which are generally known as "sandwich" courses, are a compromise between the two already mentioned; they are tending to be very favourably regarded, and in some quarters are preferred to the student training. But whatever form a scheme takes, about twelve months of "graduate" training usually follows the completion of the relevant educational course.

Although this article relates only to the education and training of an electrical engineer, it is necessary to point out that the successful completion of each of these phases still leaves the young engineer with yet a third requirement to meet before he qualifies as a chartered electrical engineer, and thereby becomes eligible for election as a Corporate Member of the Institution of Electrical Engineers. A period of at least two years of responsible experience of electrical engineering duties is prescribed for the third requirement. Added to the minimum of five years necessary for his education and training, this makes a total of at least seven years before he can be fully qualified.

FULL-TIME STUDIES WITH A GRADUATE APPRENTICESHIP

University Courses

Most electrical engineering students who follow full-time courses of study prepare for a degree in engineering at one of the universities or university colleges in the United Kingdom. Courses of this kind, usually leading to the external degree of the University of London, are also available at some of the major technical colleges.

Each university prescribes its own conditions of admission, but in general they are more or less comparable. In terms of the General Certificate of Education, which now replaces the School Certificate and Higher School Certificate examination (commonly taken until 1950 by most public and grammar school pupils), the requirements are generally as follows:

1. A pass in English language and in four or five other subjects.
2. The subjects must include: (a) a language other than English, and (b) either mathematics or an approved science.
3. At least one of the subjects must be passed at the advanced level.
4. Candidates who offer only four subjects in addition to English language must pass at one and the same sitting in two subjects at the advanced level.

At present, the examination papers at the ordinary level and those at the advanced level approximate in scope and content to the papers formerly set in the School and Higher School Certificate examinations respectively.

Because of the keen competition for places it does not follow that a student who can meet the above conditions will necessarily be accepted by a university. It is now more usual to find that students are admitted to a degree course in engineering only if they have qualified for exemption from the first year, or intermediate year as it is often called. Exemption is normally granted to a student holding a General Certificate of Education who has passed at the advanced standard in pure mathematics, applied mathematics, physics and chemistry.

A university course in electrical engineering beyond the Intermediate stage comprises three years of study, during which the examinations for the award of the degree are taken. Except in the final year, subjects studied do not vary much between the various universities. In the final year the student is usually given the opportunity to exercise a choice of subjects to enable him to specialize in one of the main branches of electrical engineering.

An indication of the scope of, and the subjects taken in, a course at one of the colleges of the University of London is given below.

First year, Intermediate (for electrical, mechanical and civil engineering students)	Pure mathematics Applied mathematics Physics Chemistry
Second year, Part I (for electrical, mechanical and civil engineering students)	Mathematics (2 papers) Applied mechanics (2 papers) Engineering drawing (1 paper) Applied electricity (1 paper) Applied heat (1 paper)
Third year, Part II (for all electrical students)	Mathematics (1 paper) Strength of materials (1 paper) Mechanisms and thermodynamics (1 paper) Electrical theory, measurements and materials (1 paper) Electrical machines (1 paper) Electrical power (1 paper) Electronics (1 paper) Electrical communications (1 paper)
Fourth year, Part III (for electrical students only)	Advanced circuit and field theory Advanced electrical measurements Properties of electrical engineering materials Metallurgy *and:* Electrical machines Electrical power *or:* Electronics Electrical communications In addition there are optional courses in mathematics, physics, mechanical engineering subjects and economics.

Apart from the Intermediate stage, the formal examinations are held in Parts I and II at the end of the second and third years respectively. But a pass or honours degree is awarded on the overall results in Parts I, II and III. Two dissertations have to be submitted during the Part III stage—one on a self-selected subject and the other on a special investigation occupying about thirty or forty working days.

Other Full-time Courses

A limited number of full-time educational courses in electrical engineering, usually extending over three years, are provided at some of the major technical colleges. In some instances the award is a diploma of the college concerned, but it is more common

for the college to obtain recognition of the award as a Higher National Diploma in Electrical Engineering. These diplomas are awarded jointly by the Ministry of Education and the Institution of Electrical Engineers to students who successfully complete a three-year course of study under approved conditions. To qualify for admission, students must either have continued the full-time general education up to the age of 17 or 18 years, or have followed a course of approved "works training" with part-time education up to that age.

Practical Training. Graduate and Pre-graduate Apprenticeships

The professional electrical engineer must be thoroughly acquainted both with the engineering techniques and processes which find common application, and with those which are more specialized and directly relevant to his particular branch. It is not necessary that he should himself be skilled in the detailed performance of the processes, although it is essential that he should understand their potentialities and limitations. Such an understanding can be acquired only by direct association with the processes and with those who perform them, and its development in the student engineer is the primary object of the systems of practical training, whether this is undertaken in the form of a graduate scheme or by means of a student apprenticeship as described below. The training required is at present most commonly available in manufacturing organizations, but the large operating concerns, such as the British Electricity Authority, are beginning to provide facilities on a big scale. In the schemes offered by the operating organizations it is generally the practice to include a period of at least six months' training with manufacturers; and often the latter take advantage of this to arrange on a reciprocal basis for their own apprentices to gain operating experience.

In 1947 the Institution of Electrical Engineers published a report, *The Practical Training of Professional Electrical Engineers*, prepared by a joint committee consisting of representatives of the British Electrical and Allied Manufacturers' Association, the Radio Industry Council and the institution. Nominees of the Post Office, and of operating organizations which now form part of the British Electricity Authority, were co-opted to be members of the committee. The information contained in the following subsections is based mainly on evidence obtained from this report.

Standard of Entry

A candidate for a graduate apprenticeship is required to have at least a pass degree. The degree course will generally have been in electrical engineering, but some firms recruit a proportion of honours graduates in physics. Candidates who have obtained an approved diploma in electrical engineering are also eligible. For acceptance as a "pre-graduate apprentice"—the name given to those in their first year of training, which is completed before proceeding to a full-time degree course—a candidate must normally have continued his general education beyond the standard for entry to a university course.

General Principles of Training

The main object of a course of practical training is to familiarize the apprentice with: (a) the materials, tools, equipment and craft skill available in modern industry; (b) the techniques and organization involved in designing, developing, manufacturing, installing and operating engineering equipment; (c) the outlook of the men for whom he is likely to be responsible in one way or another during his subsequent professional career.

Such ideas about his future career as an apprentice may have formed when he starts his training are likely to change considerably as he gains in experience. But his training will help to focus his attention on, and should encourage his development in, one or other of the seven broad groups of functional activity, namely: research, design, production, marketing, installation, operation, education.

A Typical Scheme of Practical Training

The complete course of training for those who obtain their technical education by full-time study is normally planned to last two years and frequently consists of 44 weeks of

basic mechanical training, 36 weeks of basic electrical training, and 24 weeks of what for convenience is called "office training". Pre-graduate apprentices complete most of their basic mechanical training during their pre-university year, leaving those portions of the course which need fundamental electrical knowledge until they have graduated. As they are usually released for part-time study during the academic session, the period of basic mechanical training is increased correspondingly.

Basic mechanical training is intended to give the apprentice an acquaintance with general engineering processes and techniques and to serve as an introduction to factory organization. Thus it provides an apprentice with broad workshop experience and enables him to acquire some manual dexterity, together with a knowledge of the possibilities and limitations of the processes involved in the mechanical working of materials. At the same time he also learns to appreciate the importance of human relationships in industry and some acquaintance with industrial organization. So far as the pre-graduate apprentice is concerned, the pre-university year is also intended to assure that he is suited to an engineering career and to give him a background to the more specialized training which he is expected to gain in industry both during some of the university vacations and in a post-graduate year.

The considerations can find expression in, for example, the following scheme.

Basic mechanical training (44 weeks)

Subject	Time studied (weeks)
Foundry work *or* pattern making *or* metal fabrication	8
Fitting	8
Machining	8
Special operations[1]	20

[1] This subject includes further experience in two or more departments chosen from the following list according to the branch of the industry in which the apprentice is working: pattern making, foundry work, machining, fitting, metal fabrication, working of metals, plastic moulding, rolling and drawing of non-ferrous metals, and light assembly.

The underlying purpose of the basic electrical training is much the same as for the basic mechanical training, but the electrical training necessarily varies over a wider field and normally involves some degree of product specialization. This period gives the apprentice opportunities for widening his knowledge of the properties of the materials used in electrical engineering and of the various methods employed in assembling and testing electrical equipment. A typical course is outlined below.

Basic electrical training (36 weeks)

Subject	Time studied (weeks)
Specifying and testing of materials; processes and methods of manufacture; sub-assembly; electrical testing of component parts	12
Assembly, erection and wiring of electrical equipment in one of the following branches: electrical machines, transformers and switchgear; telecommunications and industrial electronic apparatus; meters, instruments and relays; power transmission and distribution equipment (including cables and accessories); thermionic valves; electrical testing of completed equipment, diagnosis of defects and final adjustments	24

Twelve weeks may be spent in one or more departments in which the apprentice can acquire a basic knowledge of the electrical and mechanical properties of the materials used in the production of electrical equipment. The remaining 24 weeks are divided between departments in which the apprentice encounters some of the problems associated with manufacture, and give him experience of a wide variety of tests on electrical components and completed apparatus.

The period of "office training" is intended to give the apprentice the opportunity of coming into close contact with the problems of production, design and/or marketing, that are engaging the attention of the staff concerned. The first 12 weeks may be spent, for example, in a planning department, where he will assist in the preparation and implementation of production plans; and the next 12 weeks in perhaps the design or drawing office associated with the product and type of work upon which he hopes to be subsequently employed as an assistant engineer.

During one or two of his long summer vacations, an undergraduate is expected to obtain some industrial experience. But he is also encouraged to take advantage of such opportunities for, say, cultural pursuits and foreign travel and experience.

It was in the large manufacturing organizations, in which the above arrangements may be regarded as most typical, that schemes for graduate training first developed; smaller firms, however, collaborating with one another, are beginning to offer facilities almost equally comprehensive. The training provided by operating concerns is necessarily directed towards their own special requirements, but this does not make it less comprehensive or less well-founded. The main purpose of all schemes is the same, namely the provision of the practical background for the development of a fully-qualified electrical engineer, and to this end the electricity supply industry, for example, prescribes a minimum of six months with a manufacturer as an essential part of all its schemes.

PART-TIME STUDIES CONCURRENT WITH PRACTICAL TRAINING

A student apprenticeship, concurrent with part-time study at a technical college, provides an alternative method of otaining the necessary training and education to qualify as an electrical engineer. This scheme had its genesis in the "articled" apprenticeship of about half a century ago, when, on behalf of a boy who desired to make a responsible career in the profession, it was usual to enter into an agreement with a responsible engineer. On the payment of a fee, the engineer undertook to ensure that the boy would receive a comprehensive industrial training, and this background enabled him to take up in a few years time a position of engineering responsibility. The scheme, now associated with regular part-time technical study, continues to be favourably regarded in producing the engineer for the large number of posts which require a more practical background than that normally associated with the graduate scheme.

The apprentice's part-time study usually comprises courses leading to the Ordinary and Higher National Certificates in electrical engineering, which together are of five years' duration. The courses, if approved by the Institution of Electrical Engineers, are recognized, subject-for-subject, as constituting exemption from the institution's associate membership examination. It is almost invariably the practice for employers to release their apprentices at least one day a week to follow these courses. But apprentices are also expected to devote to this purpose one evening a week of their own time as well.

National Certificates in Electrical Engineering

National Certificates in electrical engineering are awarded jointly by the Institution of Electrical Engineers and the Ministry of Education under arrangements similar to those for the award of Higher National Diplomas. The part-time courses provided under the certificate scheme are classified as follows:

Senior Courses. Suitable to the needs of students who have satisfactorily completed a preparatory course of part-time study, or have had full-time continuous education up to the age of 16 years. On the successful completion of a senior course, which normally extends over three years, an Ordinary National Certificate in electrical engineering is awarded.

Advanced Courses. Adapted to the needs of older students and aim at reaching, within the limits of the subjects covered by them, the standard of university work. On the successful completion of an advanced course, which must extend over at least two years, a Higher National Certificate in electrical engineering is awarded.

An essential feature of the national certificate scheme is the discretion allowed to technical colleges in satisfying the requirements of the award. It is the responsibility of a college to initiate a course and neither the subjects nor their syllabuses are prescribed. Moreover a college sets all the examinations for its own students and marks their scripts; although, for the final examination at the end of each course, these are also assessed by persons appointed by the institution. Thus the scheme is flexible and allows the special educational needs of industry in a particular locality to be met. Some colleges provide a number of courses, for example, in electrical power and in telecommunication, which are available either during the day or in evening hours only.

The academic year at a technical college normally commences in September, and the session, which is divided into three terms by about two weeks' holidays at Christmas and Easter, continues until about the following June. As an indication of the nature of these part-time national certificate courses, the senior and advanced courses in electrical engineering provided at a technical college in a large industrial centre in England are outlined below. In order to complete the professional educational requirements of the Institution of Electrical Engineers it is usually necessary for a student to follow a further year of study beyond the range of the subject-matter for the two certificates.

Subject	Part-time day and evening course[1]		Part-time evening course[2]	
	Hours per week	Hours per session	Hours per week	Hours per session
First year				
Practical mathematics I	2½	90	2¼	72
Engineering science I	2½	90	2¼	72
Engineering drawing I	2½	90	2¼	72
Second year				
Principles of electricity I	3	108	2¼	72
Practical mathematics II	2	72	2¼	72
Engineering science II	2	72	2¼	72
Third year[3]				
Principles of electricity II (direct current and alternating current)	5	180	4½	144
Practical mathematics III	2	72	2¼	72
Light and sound *or* applied mechanics[4]	2	72	2¼	72
Fourth year				
Circuit theory and thermionics I	2	64	2	64
Electrical machinery I	3	96	2	64
Mathematics	2½	80	2¼	72
Thermodynamics *or* applied mechanics[4]	2½	80	—	—
Fifth year[5]				
Circuit theory and thermionics II	2	64	2	64
Electrical machinery II	3	96	2	64
Mathematics	2½	80	2¼	72
Thermodynamics *or* applied mechanics	2½	80	—	—

1. For the first three years, 36 weeks per session; for the following three years, 32 weeks per session.
2. For all six years, 32 weeks per session.
3. At the end of the third year the examinations for the Ordinary National Certificate are taken.
4. Optional subjects which must be taken in order to satisfy the requirements of the Institution of Electrical Engineers.
5. At the end of the fifth year the examinations for the Higher National Certificate are taken.

Subject	Part-time day and evening course: Hours per week	Part-time day and evening course: Hours per session	Part-time evening course: Hours per week	Part-time evening course: Hours per session
Sixth year or subsequently[1]				
Thermodynamics	2½	80	2¼	72
High frequency power	2	64	2	64
Radio engineering	2	64	2	64
Electronics	2	64	2	64
Electrical machine design	2	64	2	64
Electric traction	2	64	2	64
Switchgear	2	64	2	64
Electric power	2	64	2	64

N.B. Where laboratory work forms part of a subject, one-third of the time is spent in the laboratory.

[1] One or more of the subjects shown may be taken for "endorsement" on the Higher Certificate. Assessed examinations are held in the "endorsement" subjects at the end of the year in which they are taken.

PRACTICAL TRAINING. STUDENT APPRENTICESHIP

The complete course of training for those who obtain their technical education by part-time study during their apprenticeship lasts at least four, but more usually five, years. A typical course, outlined below, is modelled on the same principles as the course for graduate apprentices. It will suffice, therefore, to set it out in the barest outline, but it should be borne in mind that it is not only possible, but necessary, for apprentices entering industry at about 17 or 18 years of age to gain experience in more departments and to spend a longer period in each. Broadly, two years are devoted mainly to basic mechanical training, 18 months to basic electrical training and the remaining period to "office training" of various kinds.

Subject	Time studied (weeks)
Mechanical:	
Assembly	16
Pattern shop and/or foundry	16
Metal fabrication	8
Machining	16
Fitting	24
Special operations[1]	16
Electrical:	
Specification and testing of materials, processes and methods of manufacture; sub-assembly; electrical testing of component parts	24
Assembly and electrical testing of apparatus	44
Office:	
Planning or progress section	16
Drawing office	16
Special product training	12
Total	208

[1] See Note, page 137.

"SANDWICH" COURSES OF EDUCATION AND TRAINING

The "sandwich" scheme of education and training, which has long been an established method in certain parts of Scotland, is beginning to develop on an increasing scale in other parts of Great Britain. Much consideration is being given to the replacement of the full-time professional electrical engineering courses at technical colleges, and especially those leading to diploma awards, by sandwich courses. These enable colleges to collaborate with industry much more closely than through the full-time courses and as effectively as through the part-time courses. Moreover, in comparison with the latter, they provide the time and opportunity for a more broadly based curriculum of engineering subjects and the associated physical sciences; for this reason, too, they are tending to be preferred. An account of the principal features which are beginning to obtain in "sandwich" courses is given below.

These courses, of four or five years' duration, require, alternately, attendance at a college and training in industry for approximately equal periods in each year. But an essential characteristic is that they are "works-based", which implies that before a student is admitted he will have spent at least one year in industry on approved training and part-time education. Thereafter, the periods in college or in industry are not necessarily continuous over half a year, though each continuous period at a college is not less than a normal academic term. The industrial organizations affording the training in a particular sandwich course and the college concerned collaborate in the establishment and operation of a course. Selection, too, is made jointly by the two partners on the basis of the aptitude and ability shown by students, both in their studies and during the initial period of training.

In their early stages the training periods of these courses follow the pattern of a student apprenticeship, gradually merging in their later stages into training more in keeping with that for graduates. On the educational side the courses are at least as comprehensive as the full-time diploma courses that are available in technical colleges.

SUPERVISION OF TRAINING

However carefully a scheme of training may have been planned, satisfactory results can be expected only if the apprentices receive adequate guidance and supervision. As a result, in most organizations responsibility for the training of apprentices is in the hands of a qualified engineer, known as the education officer or manager. While a great deal of this officer's work involves close co-operation with foremen, factory supervisors and, in operating organizations, station superintendents, training is generally regarded as so important that he usually has direct access to an executive director who is concerned with long-term plans for the provision of staff and operatives.

Besides being responsible for the supervision of each apprentice's work and conduct, the engineer in charge of training ensures that each apprentice attends the required courses of instruction at the works and at the technical college. He also arranges for the transfer of apprentices from one department to another, ensuring that an apprentice's training develops in a progressive and balanced manner and, as far as possible, is in keeping with his technical studies.

It is becoming the common practice for the selection of apprentices to be left in the hands of a committee consisting of departmental chiefs and the engineer in charge of training. Apart from requiring an applicant to have reached a sufficient standard of general education, the actual selection is often made only after a candidate has spent one or two days in the works, so that both he and the committee may be in a better position to assess his suitability for training as an electrical engineer.

Student apprentices are normally recruited from public and secondary grammar schools and, to a lesser extent, from secondary technical schools. In general, they must have reached the standard of matriculation of a British university before they become eligible for consideration. As regards graduate apprentices, it is tending to become the practice for the education officers of the large organizations to visit all universities in the early part of the year to make a preliminary selection from students in the final

stages of their studies. This is usually followed by an interview at the headquarters of the organization on the lines described above, and acceptance for graduate training is given on the assumption that the students concerned will shortly qualify.

The education officer usually maintains a record of reports received from foremen or departmental heads on the work, aptitude and application of each apprentice in each department in which he had received training. These records, together with reports of the studies of the apprentice at the technical college, provide a means of assessing his progress, and by the end of his course they also give an indication of the kind of employment in which his ability can be most profitably used.

In organizations where there is a fairly large number of apprentices, including those who are training to be technicians and craftsmen as well, an apprentice association has usually grown up to provide for out-of-works activities. Such associations, which organize social, sports and other activities for the apprentices, are almost invariably run by the apprentices themselves. At technical colleges, too, such activities are also available for apprentices, as part-time students.

An increasing number of firms now provide hostels for their apprentices. Although their management is not directly the concern of the apprentice association, these hostels nevertheless foster the corporate life of the apprentice community which it is the object of the association to encourage.

ADVANCED STUDIES

The studies which an engineering apprentice has normally to complete in order to satisfy the educational requirements of the profession do not as a rule represent the total of his engineering education. It is generally recognized that there is need for him to continue to take more advanced courses in some specialized field of electrical engineering, and these are being offered on an increasing scale in all parts of the country. This advanced work usually takes one of two forms; either it is in the nature of a post-graduate course extending over a normal academic session, or, as is more usual, it comprises courses of lectures on a series of particular subjects which are normally offered on a part-time basis. Occasionally, a course of such lectures may be arranged on an intensive full-time basis extending over a period of about a fortnight or more. Both in the preparation of, and in the lectures accompanying these courses, it is the practice for experienced engineers in industry to collaborate with responsible teachers in universities and technical colleges, for it is realized that appropriate contributions from both the industrial and the educational sides, each making available its special knowledge and its perhaps different approach, can best ensure the success of the courses.

THE INSTITUTION OF ELECTRICAL ENGINEERS

Briefly, the objects of the institution, as set out in its royal charter, are to promote the general advancement of electrical science and engineering and their applications; to facilitate the exchange of information and ideas on these subjects by means of meetings, exhibitions, publications and the establishment of libraries; and to give financial assistance for the promotion of invention and research.

The institution thus fulfils a threefold purpose: it acts as a learned society to promote the dissemination of knowledge of electrical science and engineering; as a qualifying body, conferring membership on those whose qualifications fulfil the requirements of the bye-laws of the institution; and it serves as a regulating body for the profession of electrical engineering, instituting, and requiring members to observe a code of conduct as set out in the bye-laws.

These three main purposes lead in turn to many contributory activities, of which the institution's educational work is one of the most important. The members of the council take a broad view of their responsibilities in this field and are not content merely to set standards of electrical engineering education, as for example the associate membership examination, but regard it as their duty to give advice and, if necessary, assistance to those entering the profession. Furthermore, the council offers guidance on educational policy to government and educational authorities at home and abroad.

The institution makes an important contribution to the electrical literature of the world in its *Proceedings*, which reflects all aspects of the progress of electrical engineering. The *Journal* of the institution serves as a medium of communication between the council and the members on matters affecting the institution.

Another important activity is the holding of meetings at which papers are read and discussed. Papers of general interest are presented at ordinary meetings; others of more specialized interest are read before the appropriate section, of which there are four—measurements, radio, supply and utilization. All these meetings are reported in the *Proceedings*. Informal meetings are also held which are a valuable complement to the more formal proceedings. In addition, an education discussion circle encourages an exchange of views on matters of particular concern to practising teachers of electrical engineering and others having similar interests.

From the outset of their careers electrical engineers are encouraged to join the institution and to make full use of the facilities provided. In addition to receipt of its publications, the advantages of membership are brought to as many members as possible wherever they may reside. Several local centres and sub-centres have been established in many parts of Great Britain and Northern Ireland; and abroad, too, a large number of oversea branches have come into existence, particularly in countries of the British Commonwealth. There are also 14 students' sections which hold meetings for the reading and discussion of papers by students and graduates, and organize other activities of interest and value to the young engineer. The *Students' Quarterly Journal* is concerned wholly with the activities of these sections, members of which also receive copies of the institution's *Journal* and *Proceedings*.

The bibliography below gives a list of the reports on the education and training of the electrical engineer and other electrical personnel published during the past few years by the institution. The consideration given to the preparation of these reports by responsible persons actively engaged in electrical engineering and, what is equally significant, their subsequent discussion at meetings of the institution and its centres, is an indication of the importance attached—not to mention the interest shown—by the profession in the education and training of the young electrical engineer.

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Report on "The Practical Training of Professional Electrical Engineers", *Journal*, vol. 94, part I, no. 82 (October 1947), p. 437-46.

"The Organization of Post-War Electrical Research", *Journal*, vol. 90, part I, no. 31 (July 1943), p. 261-3.

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1 There are off-prints, too, of all these articles. Readers who are interested in the training of electrical engineers in Great Britain can obtain them by writing to the Institution of Electrical Engineers in London.

APPENDIX I

ABBREVIATIONS AND SYMBOLS USED IN THIS VOLUME

A = ampere
A.C. = alternating current
Ah = ampere-hour
C = capacity
°C = degrees Celsius
C.G.S. = centimetre-gramme-second (system of units)
cm = centimetre
cm^2 = square centimetre
c/s = cycles per second
db = decibel
D.C. = direct current
diam. = diameter
e.m.f. = electromotive force
F = farad
h = hour
H = henry
H.F. = high frequency (3-30 Mc/s)
H.P. = horse-power
H.T. = high tension
kc/s = kilocycles per second
kg = kilogramme
km = kilometre
kV = kilovolt
kVA = kilovolt-ampere
kW = kilowatt
kWh = kilowatt-hour
kΩ = kilohm
l = litre
L = inductance
L.F. = low frequency 30-300 kc/s)
L.T. = low tension
m = metre
m^2 = square metre
mA = milliampere
max. = maximum
Mc/s = megacycles per second
M.F. = medium frequency (0.3-3 Mc/s)
mH = millihenry
M.K.S. = metre-kilogramme-second (system of units)
mm = millimetre
mm^2 = square millimetre
M.T.S. = metre-ton-second (system of units)
mW = milliwatt
MΩ = megohm ($10^6\Omega$)
pF = picofarad (10^{-12} F)
R = resistance
R.C. = resistance-capacity circuit
r.p.m. = revolutions per minute
s = second
T.R. = transmit-receive
U.H.F. = ultra high frequency (300-3,000 Mc/s)
V = volt
V.H.F. = very high frequency (30-300 Mc/s)
W = watt
Wh = watt-hour
Ω = ohm
μA = microampere (10^{-6} A)
μF = microfarad (10^{-6} F)
μH = microhenry (10^{-6} H)
μs = microsecond (10^{-6} s)
μΩ = microhm ($10^{-6}\Omega$)

APPENDIX II

CONVERSION FACTORS

Length

1 mm	= 0.03937 in	1 mil	= 1/1000 in
1 cm	= 0.3937 in		= 0.0254 mm
1 m	= 3.2808 ft	1 in	= 25.4 mm
	= 1.0936 yd	1 ft	= 12 in
1 km	= 0.6213 mile		= 30.48 cm
		1 yd	= 3 ft
			= 0.9144 m
		1 mile	= 1609.3 m
		1 line	= 1/12 in
			= 2.116 mm

Surface

1 mm^2	= 1973.5 circular mils	1 circular mil	= 0.0005067 mm^2
1 cm^2	= 0.155 in^2	1 in^2	= 6.4516 cm^2
1 m^2	= 10.7639 ft^2	1 ft^2	= 144 in^2
	= 1.1959 yd^2		= 0.0929 m^2
1 km^2	= 0.3861 mile^2	1 yd^2	= 9 ft^2
	= 247.11 acres		= 0.83613 m^2
1 hectare	= 2.4711 acres	1 acre	= 4046.9 m^2
		1 mile^2	= 640 acres
			= 2.5899 km^2

Volume

1 ml = 1 cm^3	= 0.06102 in^3	1 in^3	= 16.387 cm^3
1 l = 1 dm^3	= 0.0353 cubic feet	1 ft^3	= 28.317 dm^3
1 m^3	= 35.3156 ft^3	1 yd^3	= 0.76456 m^3
	= 1.3079 yd^3		

Capacity

1 l	= 35.196 British fluid ounces	1 British fluid ounce	= 0.0284 l
	= 1.75981 British pints	1 British pint	= 0.5682 l
	= 0.2199 British gallons	1 British imperial gallon	= 8 British pt
			= 4.5459 l
	= 33.8140 U.S. fluid ounces	1 U.S. fluid ounce	= 0.02957 l
	= 2.1134 U.S. pints	1 U.S. pint	= 0.4732 l
	= 0.2642 U.S. gallons	1 U.S. gallon	= 3.7854 l
		1 Winchester-quart	= 80 British fluid ounces = 2.2729 l

Weight

1 g	= 0.035 oz	1 oz	= 28.35 g
1 kg	= 35.273 oz	1 lb	= 453.5 g
	= 2.2046 lb	1 cwt	= 50.802 kg
		1 oz troy	= 31.103 g

Power

1 kW	= 1.341 HP	1 HP	= 0.7457 kW

Pressure

1 kg/cm^2	= 14.223 lb/in^2	1 lb/in^2	= 0.070307 kg/cm^2
			= 95.760 pz

APPENDIX III

SHORT LIST OF SUPPLIERS OF SCIENTIFIC INSTRUMENTS

Australia

Abacus Instrument Co.
122 King St.
Melbourne

Dobbie Bros. (Thermometers)
80 Little Lonsdale St.
Melbourne

Belgium

Fédération des Entreprises de l'Industrie des Fabrications Métalliques
17, Rue des Drapiers
Brussels

Société Belge d'Optique et d'Instruments de Précision
110, Rue de la Prairie
Ghent

Denmark

Association of Scientific Instrument Manufacturers Industriraadet
18 Vestre Boulevard
Copenhagen 5

H. Struers Chemiske Laboratorium
38 Skindergade
Copenhagen

France

Association Interprofessionnelle des Constructeurs de Matériel d'Equipement Scientifique (AICMES)
(12 member federations comprising 165 firms)
61, Rue de Malte
Paris, 11e

FOPEX (group of 32 industrials)
61, Rue de Malte
Paris, 11e

Great Britain

Scientific Exports (Great Britain) Ltd. (SCIEX) (comprising 7 firms)
Buckingham House, Buckingham St.
Adelphi, London, W.C.2

Scientific Instrument Manufacturers' Association of Great Britain Ltd. (SIMA) (comprising 84 firms)
17 Princes Gate
London, S.W.7

Italy

Associazione Nazionale degli Industriali del Vetro
2 Via Regina Elena
Rome

Associazione Nazionale Industria Meccanica e Metallurgica
3 Piazza Mignanelli
Rome

Netherlands

Vereeniging van Nederlandsche Instrumentfabrikanten
73 Voorstraat
Delft

Sweden

Rudolph Grave Aktiebolaget
48 C Malmskillnadsgatan
Stockholm

Norstedt & Soner
17 Bryggaregatan
Stockholm

Axel Kistner
20-22 Wallingatan
Stockholm

Switzerland

Association Suisse des Constructeurs de Machines (V.S.M.)
4, General Wille Strasse
Zürich 2

United States

Scientific Apparatus Makers of America (SAMA) (comprising 202 firms)
20 N. Wacker Drive
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